Fisheries and Oceans Science Pêches et Océans Sciences

CSAS
Canadian Science Advisory Secretariat

SCCS
Secrétariat canadien de consultation scientifique

Proceedings Series 2001/033 **Série des compte rendus 2001/033**

PROCEEDINGS OF THE

WORKSHOP

ON THE

CANADIAN CONTRIBUTION TO THE LIVING MARINE RESOURCES (LMR) MODULE OF THE GLOBAL OCEAN OBSERVING SYSTEM (GOOS)

Bedford Institute of Oceanography
29-30 March 2000

Glen Harrison/Michael Sinclair, *Co-Chairs**
*Contributors***: David Agnew, Rod Bradford, Jim Boutillier, Jean-Claude Brêthes, Villy Christensen, Roger Doyle, Paul Fanning, Don Gordon, Ellen Kenchington, Serge Labonte, Bob Mohn, Jack Musick, Savi Narayanan, Pierre Pepin, Ian Perry, Jim Reist, Jake Rice, Gary Sprules, Ed Trippel, and Kees Zwanenburg

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Foreword

The purpose of this proceedings is to archive the activities and discussions of the meeting. including research recommendations, uncertainties, and to provide a place to formally archive official minority opinions. As such, interpretations and opinions presented in this report may be factually incorrect or mis-leading, but are included to record as faithfully as possible what transpired at the meeting. No statements are to be taken as reflecting the consensus of the meeting unless they are clearly identified as such. Moreover, additional information and further review may result in a change of decision where tentative agreement had been reached

Avant-propos

Le présent compte rendu fait état des activités et des discussions qui ont eu lieu à la réunion, notamment en ce qui concerne les recommandations de recherche et les incertitudes; il sert aussi à consigner en bonne et due forme les opinions minoritaires officielles. Les interprétations et opinions qui y sont présentées peuvent être incorrectes sur le plan des faits ou trompeuses, mais elles sont intégrées au document pour que celui-ci reflète le plus fidèlement possible ce qui s'est dit à la réunion. Aucune déclaration ne doit être considérée comme une expression du consensus des participants, sauf s'il est clairement indiqué qu'elle l'est effectivement. En outre, des renseignements supplémentaires et un plus ample examen peuvent avoir pour effet de modifier une décision qui avait fait l'objet d'un accord préliminaire

TABLE OF CONTENTS

Abstract 5

Résumé 6

Executive Summary 7

1 Monitoring of Living Marine Resources in the Context of Scientific Research and Advice 17

- *1.1 Definition* 17
- *1.2 LMR Monitoring in the Context of Other Activities* 18
- *1.3 LMR Monitoring as a Subset of Other Monitoring Activities* 19
- *1.4 Monitoring in the Context of Scientific Research* 19
- *1.5 LMR Monitoring in the Context of Dynamical Systems* 19

2 LMR-GOOS 22

- *2.1 LMR and National Issues* 22
- *2.2 LMR International* 23

3 Definition of Approach 25

- *3.1 Elements* 25
- *3.2 National Approach* 26

4 Ecosystem Objectives 27

5 Indicators 29

6 Workshop Presentations and Discussion 32

- *6.1 Objective #1 Ecosystem Diversity (P. Pepin, Rapporteur)* 32
- *6.2 Objective #2 Species Diversity (J. Reist, Rapporteur)* 34
- *6.3 Objective #3 Genetic Diversity Within Species (J. Reist, Rapporteur)* 38
- *6.4 Objective #4 Exploited Species (J. Boutillier, Rapporteur)* 41
- *6.5 Objective #5 Non-exploited Species (J. Boutillier, Rapporteur)* 43
- *6.6 Objective #6 Emergent Properties of Ecosystems (P. Pepin, Rapporteur)* 45

7 Issues 47

- *7.1 Infrastructure* 47
- *7.2 Next Step?* 48

8 Recommendations 48

9 Appendices **52**

9.1 Workshop Agenda *52*

9.2 List of Participants *53*

9.3 Presentation outlines, Abstracts, Working papers and Respondent comments *54*
9.3.1 Objective #1: Ecosystem Diversity 54
9.3.2 Objective #2: Species Diversity 59
9.3.3 Objective #3: Genetic Variability Within Species 64
9.3.4 Objective #4: Exploited Species 73
9.3.5 Objective #5: Non-exploited Species 92
9.3.6 Objective #6: Emergent Ecosystem Properties 93

10 Addendum **116**

Abstract

The goal of LMR-GOOS is to provide operationally useful information on changes in the state of living marine resources and ecosystems, i.e. observational services and forecast to those concerned with the harvest, conservation and scientific investigation of living marine resources of the deep ocean and shelf seas.

In order to fulfil this goal, a comprehensive ecosystem and environmental observational program is required which identifies variables and parameters of importance for detection of changes in structure, behavior and bio-diversity, including the status of fishery resources.

Within Canada, discussions on LMR-GOOS were initiated by DFO in January, 1999 at the workshop to develop the Canadian contribution to the Climate Module of GOOS. Among the recommendations coming out of that workshop was the suggestion of a follow-up workshop focussing specifically on LMR. The purpose for LMR-GOOS workshop held at the Bedford Institute of Oceanography (29-30 March, 2000) was to begin the process of developing a framework for Canada's contribution to LMR based on (1) identification of *ecosystem objectives* for integrated oceans management and conservation and (2) definition of the *indicators* by which the observational tools we will employ to monitor the ocean ecosystem can be assessed.

Approximately 35 scientists and managers, including members of the Ad Hoc DFO committee on GOOS, other DFO (including Oceans Sector) representatives and national and international university experts, participated in the two day workshop. The workshop was structured around presentations by DFO scientists on six proposed ecosystem objectives and associated indicators and extensive follow-up discussion lead by outside experts. The goal of the workshop was to determine if this is the appropriate conceptual framework for Canada to follow in developing a national LMR monitoring program and to gain a broader perspective on the list of indicators that will be required to determine and prioritize the ecosystem features to be monitored and monitoring products required.

Résumé

Le système LMR-GOOS vise à fournir des renseignements opérationnels utiles sur les changements survenant dans l'état des ressources marines vivantes et des écosystèmes marins, par exemple des services d'observation et de prévision à ceux qui sont concernés par la récolte, la conservation et l'étude scientifique des ressources marines vivantes des eaux océaniques profondes et des mers épicontinentales.

Cet objectif nécessite un programme exhaustif d'observation des écosystèmes et de l'environnement qui définit des variables et des paramètres importants pour la détection des changements dans la structure, le comportement et la biodiversité de ces ressources et écosystèmes, y compris dans l'état des ressources halieutiques.

Au Canada, le MPO a amorcé des discussions sur le système LMR-GOOS en janvier 1999, à l'atelier organisé pour établir la contribution canadienne au module sur le climat du GOOS. Parmi les recommandations formulées à cette occasion, il avait été suggéré de tenir un atelier de suivi portant spécifiquement sur les LMR. À cet atelier LMR-GOOS, qui s'est tenu à l'Institut océanographique de Bedford les 29 et 30 mars 2000, on entendait lancer le processus d'élaboration du cadre de la contribution canadienne concernant les LMR en se fondant sur 1) l'établissement des objectifs écosystémiques pour la conservation et la gestion intégrée des océans et 2) la définition des indicateurs servant à évaluer les outils d'observation que nous utiliserons pour surveiller l'écosystème océanique.

Environ 35 scientifiques et gestionnaires, y compris des membres du comité spécial du MPO sur le GOOS, d'autres représentants du MPO (notamment du Secteur des océans) et des experts universitaires canadiens et internationaux, ont participé à l'atelier de deux jours. Ce dernier s'articulait autour de présentations par des scientifiques du MPO sur les six objectifs écosystémiques proposés et sur les indicateurs connexes, et autour également de discussions de suivi exhaustives menées par des experts externes. L'atelier avait pour but de déterminer si la bonne approche conceptuelle consistait pour le Canada à élaborer un programme national de surveillance des LMR et à acquérir une perspective plus large quant à la liste des indicateurs et des produits qui seront nécessaires pour définir et prioriser les éléments de l'écosystème.

Executive Summary

Background

The goal of LMR-GOOS is to provide operationally useful information on changes in the state of living marine resources and ecosystems, i.e. observational services and forecast to those concerned with the harvest, conservation and scientific investigation of living marine resources of the deep ocean and shelf seas.

In order to fulfil this goal, a comprehensive ecosystem and environmental observational program is required which identifies variables and parameters of importance for detection of changes in structure, behavior and bio-diversity, including the status of fishery resources.

Within Canada, discussions on LMR-GOOS were initiated by DFO in January, 1999 at the workshop to develop the Canadian contribution to the Climate Module of GOOS. Among the recommendations coming out of that workshop was the suggestion of a follow-up workshop focussing specifically on LMR. The purpose for LMR-GOOS workshop held at the Bedford Institute of Oceanography (29-30 March, 2000) was to begin the process of developing a framework for Canada's contribution to LMR based on (1) identification of *ecosystem objectives* for integrated oceans management and conservation and (2) definition of the *indicators* by which the observational tools we will employ to monitor the ocean ecosystem can be assessed.

The two-day workshop was structured around presentations by DFO scientists on six proposed ecosystem objectives and associated indicators followed by extensive discussion lead by outside experts. An important goal of the workshop was to determine if the ecosystem objectives approach is the appropriate conceptual framework for Canada to follow in developing a national LMR monitoring program and to gain a broader perspective on the list of indicators that will be required to determine and prioritize the ecosystem features to be monitored and monitoring products required.

Monitoring Principles and Approach

Before defining ecosystem objectives and indicators, however, a more general definition of monitoring is required. Monitoring of living marine resources is defined as repeated (usually regular) and sustained observations of biological organisms over the long term. Given the complexity of biological systems and the potential responses of the living components to outside factors, monitoring must encompass collection of critical abiotic properties as well as biological ones. Living resources are naturally structured at several levels of organization. Thus, monitoring programs must be similarly structured. These levels include:

1. attributes of individuals such as simple biological properties (e.g., size or age), complex properties (e.g., condition factor), and aspects such as genotypes;
2. attributes of biological populations such as size or age distribution of individuals, composition based upon different types (e.g., sex ratio, mature and immature), genetic variability, spatial or temporal extent, etc.;
3. attributes of species such as population composition, genotypic variability, composition of life history types or similar variants, spatial or temporal extent, etc.; and,

4. attributes of ecosystems such as diversity of species present, habitat composition, relative abundance of species, size spectrum, etc.

Ecosystems and their biotic and abiotic components are inherently dynamic, exhibiting regular cyclical as well as random changes. Thus, it is important to define at the outset the detection of what type of change is being sought when monitoring and to have the capability of differentiating the "signal" from the natural background "noise". Discerning directional change (e.g. long-term "trends") and perturbation of cycles from regular, normal cyclical change and attributing cause to those changes are integral to proper monitoring. This is especially true for evaluating the acceptability of the change and for developing mitigative or adaptive responses to the changes.

The general approach to monitoring living marine resources within a global ocean observing system is based on four essential elements:

1. Recognition that a central goal of an observing system is to detect "changes" in the state of the system, and to detect these changes rapidly. Ecosystems are dynamic, such that they undergo changes routinely on a variety of time scales (e.g. seasonal changes), but they also show stability, so that particular marine ecosystems are often described as "cod" or "crab and shrimp" systems, etc. It is usually this latter property ("stability") that is of major concern when the system appears to suddenly shift from one state to another. It is these types of changes that need to be detected quickly.
2. An understanding (definition) of the spatial domain being monitored, which in some sense is representative of the ecosystem. These spatial domains may be set for practical reasons, such as jurisdictional boundaries, or they may be set for habitat or species distributional reasons. However they are defined, there is usually at least an implicit sense of the spatial domain being represented by the monitoring program. One of the early research requirements of the program is to establish the spatial (and temporal) scales over which particular observations are representative.
3. Definition of data products. These are what are usually considered as the outcomes from monitoring programs, e.g. the hydrographic conditions at a particular time and place, or the abundance of a particular species of fish. They are also clearly related to the time and space scales of the underlying processes that they represent. The particular choice of what to monitor, the indices that result, and the products that are produced are crucial to the long-term success of a monitoring program.
4. Establishment of a data management strategy. Without an explicit and formal system (with timelines) for analysing observations and submitting data to a central storage system, the monitoring program will bog down and collapse. Rapid detection of "change" requires rapid availability of the data. Any long-term program also needs strong institutional support for it to continue; this support can be best assured through rapid data availability and accessibility by a broad user community – i.e. broader than those conducting the monitoring program.

Ecosystem Objectives and Indicators

Within Canada, the responsibility for the planning and implementation of ocean monitoring rests primarily with the Department of Fisheries and Oceans (DFO). Collaborations have been established with other departments and agencies to include those variables for which the responsibility falls outside DFO. Within this framework, ocean monitoring programs have been (or are being) developed for the ocean off both the Atlantic and Pacific coasts and to a lesser extent for the Arctic. These programs have been designed to meet various Canadian requirements for marine environmental information and have elements that encompass Coastal GOOS (C-GOOS), Living Marine Resources (LMR) and Health of the Ocean (HOTO) needs. Some elements are presently being routinely observed as part of existing monitoring and research programs.

Under the 'Canada Oceans Act', Canada has placed considerable emphasis in developing coastal zone management strategies and designating various ecologically sensitive areas as 'Marine Protected Areas'. Furthermore, Canada does have operational programs in these areas, especially as they relate to fisheries, fish habitat and overall marine environmental quality. In an effort to evaluate the effectiveness of current monitoring programs in meeting Canada's ecosystem objectives for integrated oceans management and conservation a number of national workshops have been held or are proposed.

The 1992 Convention for Biological Diversity (CBD), the Straddling Stocks Convention (UNFA), and the Code of Conduct for Responsible Fishing have generated broader conservation objectives for the management of ocean use activities. The 1997 Oceans Act obliges Canada to incorporate ecosystem objectives within an integrated oceans management framework. The pending legislation addressing species at risk of extinction will generate recovery plans for endangered marine species. Thus we are in a transition period with respect to the need for scientific advice on management of ocean uses (oil and gas, aquaculture, marine transportation, eco-tourism, recreational use and fisheries). Management will continue to occur at the sectoral level, yet the aggregate activities need to meet some yet to be defined ecosystem objectives. The scientific advisory context for LMR-GOOS is in transition. Fisheries management needs to take into account ecosystem considerations, and other ocean uses have impacts on the ecosystems that need to be evaluated in relation both to the fisheries impacts and the broader conservation objectives inferred under new international conventions and national legislation.

The ICES/SCOR Symposium on the Ecosystem Effects of Fishing, held in Montpellier in March 1999, provided some guidance on a framework for the incorporation of ecosystem considerations within fisheries management. The Symposium overview paper (Gislason et al. 2000) lists six potential ecosystem objectives for oceans management, three address biodiversity and three habitat productivity. The traditional conservation objective for the target species of fisheries management is subsumed within the latter three.

For each objective there will be a need to define indicators of relevance as well as reference points that trigger management action. Indicators should have three key attributes: they should be measurable, interpretable and sensitive to changes in biotic or environmental change. At the Canadian LMR-GOOS workshop at BIO there was a detailed review and discussion of indicators for each of the six objectives introduced at the Montpellier symposium. To the degree that a region wants to achieve a particular objective, LMR-GOOS for that ocean area needs to monitor properties that will generate data products on the respective indicators. At the BIO workshop, indicators were discussed for each of the six potential ecosystem objectives:

Objective #1: Maintenance of Ecosystem Diversity

The benthos is considered separately from the pelagic component of the marine biota. Due to recent advances in multi-beam and side-scan sonar it is now possible to routinely map the bottom sediment type and relate this to the number and geographic pattern of bottom communities in 'benthic ecosystems' that need to be maintained. The indicators to be monitored are:

- the spatial extent of disturbance (by fish gears, oil/gas operations, aquaculture sites, etc.) for each category of benthic habitat in the classification scheme, and
- benthic community properties in 'no disturbance' areas (e.g., MPAs) and disturbed areas for each benthic ecosystem type.

For this objective it is assumed for planning purposes that some percentage of each habitat type would need to be undisturbed.

For the pelagic and fish components of the biota the geographic scales of ecosystems/communities are much larger, e.g. Longhurst (1998) areas for plankton. The indicators would be:

- measures of geographic patterns in plankton and fish community structure.

The present monitoring activities in the Atlantic (CPR line, seasonal zooplankton net hauls on transects from AZMP, ecosystem trawl survey from Cape Hatteras to Cape Chidley) should be sufficient to generate some of the data products for the indicators.

Objective #2: Maintenance of Species Diversity

The minimum required for this objective is to provide indicators for the recovery plans of the species at risk of extinction. The indicators need to be considered at the geographic scale of evolutionary significant units (ESUs), and are species specific. They include:

- Rate of population decline (decline in abundance and absolute population size, abundance fluctuations),
- Contraction in distributional area (extent of occurrence, area of occupation),
- Number of spawning components (population fragmentation),
- Number of individuals and effective population size (Ne),
- Other population and individual characteristics (No. of mature individuals, age of maturity, rarity, growth rate, fecundity, recruitment rate),
- 'Integrity' of essential habitat,
- By-catch and mortalities due to other human activities.

Objective #3: Maintenance of Genetic Variability within Species

The indicators for this objective have some overlap with that above, but need to be considered for a much wider range of species, in particular for species that are commercially exploited. There are at least two high profile concerns, the loss of spawning components and the reduction in genetic variability within populations (both due predominantly to fishing practices). The potential indicators include:

- Census (total population size) and effective population size (Ne) per generation,
- Number of populations,
- No. of progeny per parent,
- Sex ratio
- Selection differential for life history parameters such as size-at-age and age-at-maturity,
- Mutation and gene flow,
- Evolvability,
- Co-evolution,
- Nearest neighbor estimates for sessile invertebrates.

Objective #4: Maintenance of Exploited Species

This objective subsumes the need to prevent growth and recruitment overfishing of the commercial species targeted. The traditional indicators would be:

Surveys-based
- Stock size (inc. spawning stock biomass, B),
- Exploitation rate (fishing mortality, F),
- Recruitment to stock.

Recently there has been a move to broaden the scope of the indicators to include such measures as:

Biological
- Size/age composition of population,
- Growth rate of target spp.,
- Condition of target spp.,
- Areal distribution of stock,
- Stock reproductive potential.

Environmental/ecological
- Predator (on target spp.) abundance,
- Prey (of target spp.) abundance.

Fishery
- Spatial distribution of catches,
- Fishing effort/trends in catch per unit effort,
- Discards of target spp.,
- Recent trends in biomass and recruitment,

- Compliance of fishers to regulations.

With the use of a broader range of indicators a qualitative stop-light approach (green/yellow/red ratings by indicator) is envisioned, which would complement the present use of quantitative assessment models.

Objective #5: Maintenance of Non-exploited Species

This objective addresses the importance of food-chain interactions amongst the target species of commercial fisheries and the key predators on such species. It is of particular interest for fisheries on forage species such as krill and small pelagics. The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) has been a leader on how to deal with this ecosystem consideration. There are two approaches. The first was the traditional indicator for the target species (F and B), but takes into consideration that a larger biomass should be sustained than is the case under traditional fisheries management approaches. In essence the reference point for biomass of the target species changes, but the indicators stay the same. The second approach includes the monitoring of key predators of the targeted forage species under commercial exploitation. Indicators could include:

- Abundance of key predators of exploited spp.,
- Condition of key predators,
- Percentage of commercially harvested prey spp. in diet of key predators.

Objective #6: Maintenance of Emergent Ecosystem Properties

This class of objectives addresses emergent properties of ecosystems, and is somewhat controversial. There is a need to monitor properties of marine biological communities that are indicators of their structure and function, even though at this time there is not a consensus on optional states of trophic level balance. Indicators could include:

- Indices of diversity (richness, evenness, dominance),
- Slope of size (No. or biomass) spectra, k-dominance curves, abundance-biomass comparisons across communities (ABC curves),
- Pauley's Fisheries in Balance (FIB) index,
- Aggregate removals by fishing at each trophic level.

Additions to Present Monitoring Activities

The Canadian LMR-GOOS workshop indicated a need to augment present monitoring activities if the broader ecosystem objectives are to become components of an integrated ocean observational program. The additions would include:

- Bottom areas disturbed by ocean use activities,
- Benthic community monitoring in disturbed and undisturbed areas by habitat type,
- Targeted surveys for species-at-risk,
- By-catch of species-at-risk and other mortalities due to human activities,
- Numbers and locations of spawning populations for exploited species,

- Selection differentials for certain exploited species,
- Sex ratio of exploited species,
- Condition, abundance and food habits of selected key predators on forage species.

Research Needs in Support of Monitoring

A key challenge in the transition to integrated management of ocean uses is the need to assign *causality* to observed charges in marine ecosystems. If a change is observed in an indicator will we be able to associate that change with natural environmental variability or impacts of a particular ocean industry (e.g. oil/gas, aquaculture, fishing). Thus it is essential to monitor a broader suite of oceanographic and atmospheric indicators that allow description of natural climate variability and modeling of impacts.

Infrastructure and Data Management

A program as large as LMR GOOS needs to consider the administrative needs of its implementation. Two aspects of this are program management (how the project is coordinated and managed) and data management (how the data products are processed and archived). Both are critical aspects of any large-scale program such as LMR GOOS. LMR GOOS will need strong central coordination if it is to be a success. This could be achieved though establishment of a National Coordination Office. This office would ensure that the program remains relevant and funded, and that the latter is sustained and predictable. It would serve as a focus for interaction with other levels of government and other countries, and facilitate public and political awareness. An important role of the National Coordination Office would be coordination of bottom-up research priorities with top-down strategic priorities defined by national agencies. This would greatly improve the chances for strategic funding.

Likewise, the integration of data management is of central importance to the success of the LMR GOOS program. Data integration problems associated with large-scale programs such as LMR-GOOS were recently highlighted as part of the DFO Science Strategic Plan. As a consequence, a DFO data management policy has been developed and will be in place for 2000 – 2001. This policy should be used to direct data management in LMR GOOS.

The Next Step

Canadian representatives from both DFO and universities continue to participate in the development of the international strategic design and implementation plans for the two GOOS panels, the Coastal Ocean Observations Panel (COOP) and the Ocean Observations Panel for Climate (OOPC); since the workshop, LMR, C-GOOS and HOTO were amalgamated into COOP. The ecosystem objectives framework proposed for LMR has been put forward for the broader COOP monitoring system as well as for ICES consideration.

Nationally, dialog among government and NGO scientists, managers and stakeholders continue in an effort to better define ocean management areas (OMAs) and ecosystem objectives and to develop relevant, interpretable and practical indicators. Ultimately, DFO will determine the ecosystem objectives for integrated oceans management with input from other departments and stakeholders. In parallel, efforts are underway to develop a national monitoring strategy that will identify core observations and insure some consistency in data collection and products across regions while still preserving region- specific requirements.

Some discussion at the BIO workshop wrap-up revolved around how this will be accomplished. Among the suggestions posed was a proposal for a series of regional workshops to "operationalise" the process by, for example, developing regional "pilot" projects, an approach similar to that adopted by international LMR-GOOS. Concern was expressed, however, that small pilots may not carry with them a commitment for long-term funding once the pilots are completed. Sustained funding is fundamental for the implementation of a long-term monitoring program. A suggested alternative is to define a large program now, secure the funding and then consider pilots to fine-tune or "regionalise" the monitoring network. To develop the national program, working groups for each of the ecosystem objectives would be struck to define and establish needs. These WGs would put together proposals addressing the identified needs that would then be passed on to a National Coordination Office tasked to review the proposals and use that information to define common infrastructure elements. This would then be sent back to the WGs for final consideration. The approach that will ultimately be used to carry this forward is still in the planning phase.

Following LMR-GOOS workshop, two additional DFO workshops were held to further clarify and define the ecosystems objectives framework for addressing issues at the regional (Workshop on the Ecosystem Considerations for The Eastern Scotian Shelf Integrated Management – ESSIM- Area, BIO, 19-23 June, 2000) and national level (National Workshop on Objectives and Indicators for Ecosystem-based Management, Sidney, BC, 27 Feb-2 Mar, 2001). In addition, an international workshop was convened to begin the process of merging the GOOS non-climate modules, LMR, C-GOOS and HOTO, into a single panel, the Coastal Ocean Observations Panel COOP (Coastal Ocean Observations Panel, Session I, San Jose, Costa Rica, 15-17 Nov, 2000). The recommendations outlined below, therefore, reflect points raised during the LMR-GOOS workshop and as well some points raised during subsequent workshops as they relate to Canada's role in GOOS. The recommendations have been grouped into three categories; strategic, administrative and research.

Strategic Recommendations

1. The ICES/SCOR Symposium on the Ecosystem Effects of Fishing, held in Montpellier in March 1999, provided an operational framework for the incorporation of ecosystem considerations within fisheries management. The framework was subsequently accepted by DFO Policy Committee (June 2000) as part of the approach to the incorporation of ecosystem objectives within fisheries and oceans management. It is recommended that this framework be adopted as a starting point for the development of a "living marine resources" observing program for Canada, and presented to COOP-GOOS for their consideration as an international template.

2. ICES/IOC has formed a Steering Group for the coordination and implementation of GOOS activities in the North Atlantic. It is recommended that Canada use this mechanism for the development of COOP components of GOOS with United States (and possibly with France and Denmark for St. Pierre and Miquelon and Greenland issues).

3. PICES has formed a working group to address monitoring needs for the North Pacific. It is recommended that Canada use this mechanism for the development of COOP components of GOOS with relevant nations in the North Pacific.

4. There are numerous international planning activities directed at climate and ecosystem monitoring in the arctic, under the auspices of the Arctic Council (including programs such as the Arctic Monitoring and Assessment Programme [AMAP] and Conservation of Arctic Flora and Fauna [CAFF)]), and the International Arctic Science Committee (IASC) and the Arctic Ocean Sciences Board (AOSB) among others. Nationally, DFO has included Arctic Ocean monitoring in its submissions to the Climate Change Action Fund. It is recommended that Canada use these mechanisms for the development of COOP components of GOOS with relevant nations in the arctic.

5. The ecosystem trawl surveys conducted by DFO and NMFS along the eastern seaboard from Cape Hatteras to Cape Chidley provides an exceptional data set to monitor large scale long term changes in fish and invertebrate demersal communities. It is recommended that DFO contact NMFS about merging the data sets from the relevant trawl surveys and propose this biological observational program as an Initial Observing System for the COOP component of GOOS.

6. Canadian participation in LMR, HOTO and Coastal panels has been active, including DFO and University members. At present Keith Thompson and John Cullen from Dalhousie University are expert members of COOP-GOOS and Savi Narayanan has been the national representatives. It is recommended that DFO continue to participate actively in the COOP GOOS Panel.

Administrative Recommendations

7. The "living marine resource" monitoring programs in the Pacific, Arctic and Atlantic are at different stages of development. It is recommended that a DFO national COOP Working Group (C-COOP WG) be established to coordinate the development and implementation of the Canadian COOP program. The C-COOP WG would report to NSDC.

Research Recommendations

8. The proposed ecosystem objectives and indicators for integrated oceans management need to be more clearly defined so that there is a common understanding by both specialists and stakeholders. It is recommended that the ecosystem objectives and indicators, as elaborated upon at the DFO Dunsmuir Workshop (February 2001), be described in an operational and easily understood manner.

9. Some gaps in the present monitoring activities relative to the generation of data products for the indicators of ecosystem objectives were identified during the workshop. It is recommended that an evaluation of the state of the ecosystem for the northwest Atlantic be carried out initially using the AZMP observations, and other relevant data from fisheries monitoring activities. This should be expanded to include observational data from other regions (Pacific, Arctic) subsequently. The "state of the ecosystem" would be described in relation to the proposed ecosystem objectives for integrated oceans management.

10. For proposed objective 1, the maintenance of "diversity of ecosystem types" there is a need for the spatial classification of the benthos, pelagic and fish communities within Canada's EEZ. There is also a need for the definition of the geographical proportions of the diverse ecosystem types that need to be protected from disturbance by categories of ocean industry activities. This later need is particularly acute for benthic communities. It is recommended that research be carried out in support of spatial classification of "ecosystem types" and the use of zoning of ocean uses for their protection.

11. For proposed objective 2, the maintenance of species diversity, there is a need for improved definition of evolutionary significant units (ESUs) for marine "species of special concern". It is recommended that research on ESUs for such species be supported, as a prerequisite for establishment of spatial scales for monitoring.

12. For proposed objective 3, the maintenance of genetic diversity within species, it was evident that monitoring of this level of marine biodiversity is in the exploratory phase and could be very costly. It is recommended that, as a start, the spatial distribution of spawning aggregations of "species of special concern", as well as for commercially exploited species, be part of relevant monitoring programs.

13. For proposed objective 4, the maintenance of commercially exploited species, it was recognized that the fishing industry, First Nations as well as DFO conduct relevant monitoring activities. It is recommended that multiple indicators be explored (in addition to traditional indicators of stock biomass, recruitment and fishing mortality), and that the traffic-light approach be further developed for analysis of the indicators.

14. For proposed objective 5, maintenance of dependent species, the approach being taken by **CCAMLR** was considered to be useful. It is recommended that the fisheries monitoring programs collecting by-catch information be routinely analyzed, and data products be reported on.

15. For proposed objective 6, maintenance of emergent properties of marine ecosystems, it was recognized that gaps in understanding of ecosystem structure and function make it difficult to arrive at consensus on useful indicators. It is recommended that a range of indicators of properties of marine ecosystems be reported on in an exploratory manner.

16. For the interpretation of the causes of observed changes in indicators for the proposed ecosystem objectives (in relation to natural variability and diverse impacts of ocean industries), it was recognized that the "living marine resource" monitoring system needs to include observations beyond those that generate the data products for the indicators. It is recommended that the Canadian COOP-GOOS monitoring program include measures of oceanographic properties (physical and biological) necessary for the assessment of causality.

17. It was recognized that there is a shortfall in resources for the routine analysis of data presently being generated by diverse monitoring activities of relevance to COOP-GOOS. It is recommended that the NSDC consider steps to be taken to strengthen capacity for analyses of monitoring programs, including the role of modelling tools.

1 Monitoring of Living Marine Resources in the Context of Scientific Research and Advice

1.1 Definition

Monitoring of living marine resources is defined as repeated (usually regular) an sustained observations of biological organisms over the long term. Monitoring should not be done outside of a context, thus it is usually directed towards a specific aim. This aim sets the limits, nature, periodicity, and other related aspects of the monitoring. Clearly defined goals or objectives will result in well-documented monitoring which will capture the basic observations needed. Monitoring is conducted to assess change, or its complement, stability in a system. Given the complexity of biological systems and the potential responses of the living components to outside factors, LMR monitoring should encompass collection of critical abiotic properties as well as biological ones. Therefore, the aims and objectives of monitoring should be used primarily as guidelines and not as restrictive parameters to eliminate easily captured companion data. Much value has resulted from re-examining 'monitoring' data collected for one specific purpose in the context of new understanding, often long after the original data were collected. As a consequence, there is value in obtaining as much data as is feasible in monitoring programmes, even if some may not be specifically applicable to the immediate goals of that particular monitoring project. This value-added aspect is only feasible provided that (a) such collection does not compromise the original aims of the programme, and, (b) such data along with those specifically collected for the monitoring programme are adequately documented, integrated, disseminated, and archived over the longer term.

In addition to detecting change, monitoring can aid in differentiating natural variability from long-term anthropogenic trends resulting from exploitation, development, pollution and global change. Distinguishing natural variability from that caused by human activities (i.e. "signal to noise") is critical in assigning cause to observed change and for developing mitigative and adaptive responses to the change. Monitoring can also aid in the evaluation of the efficacy of conservation measures for biota, their habitats and ecosystems.

Living resources are inherently naturally structured at several levels of organization. Thus, monitoring programs need to be similarly structured. These levels include:

a) attributes of individuals such as simple biological properties (e.g., size or age), complex properties (e.g., condition factor), and aspects such as genotypes;
b) attributes of biological populations such as size or age distribution of individuals, composition based upon different types (e.g., sex ratio, mature and immature), genetic variability, spatial or temporal extent, etc.;
c) attributes of species such as population composition, genotypic variability, composition of life history types or similar variants, spatial or temporal extent, etc.; and,
d) attributes of ecosystems such as diversity of species present, habitat composition, relative abundance of species, size spectrum, etc.

Note that in the above, the concept of biological population is defined as a cohesive, naturally occurring, self-reproducing biological unit which is distinct from other such co-extensive units of the same species. Such biological populations are referred to as biological stocks, genetic stocks, or populations and are often different from so-called fishery stocks. Also inherent in the above is the implication that biological stocks, species and ecosystems are all definable, and, in fact, defined for the monitoring programme being undertaken. That is, appropriate natural boundaries must be placed around the system to make the monitoring programme sensible and relevant. If biological stocks or species are not defined, then appropriate preliminary work to do so must be conducted to provide the natural context for organising monitoring data and for observing change or stability in the biota. Failure to conduct this necessary first step limits but does not necessarily preclude the applicability of monitoring programmes – however, what is being monitored must be adequately defined *a priori*. This is an important but often overlooked point. It is important because living organisms, especially larger ones, are capable of movement from place to place. Such mobility is often in response to changing conditions and, over time populations may be supplanted by others. Thus to properly interpret any changes, the monitoring data must be associated with the proper biological population.

Important also is the association of individuals, populations or species with place. Thus, place provides the context within which LMR monitoring occurs. Of course, for marine biota that occupy three-dimensional habitats, place includes a geographic as well as a depth context. As noted above, in addition to monitoring the biotic components of marine ecosystems, it is essential also to monitor critical abiotic properties of the space the organisms occupy that are known or suspected to affect the biotic components. That is, in order to be effective, efficient and offer the best chance for understanding, LMR monitoring must, of necessity, include appropriate description and monitoring of the habitat(s) the organisms occupy.

1.2 LMR Monitoring in the Context of Other Activities

The goal of monitoring is to detect change or conversely stability in some property(s) or aspect of the living marine system, related habitats, and the ecosystem of which they are a part (Fig. 1.1). Such observations when placed in context allow for understanding of the system, documentation of changes to it, and, most importantly, responses regarding the acceptability of the change. Subsidiary benefits include better advice and ways of doing things, and clues regarding needs for additional monitoring and/or research. That is, monitoring (the inductive accumulation of information) is linked to research through the deductive process of hypothesis development and subsequent testing. Greater understanding as a result of monitoring permits timely response to change, enhanced ability to anticipate or predict future changes, and to manage change effectively. Monitoring and increased understanding also enhance our ability to integrate LMR monitoring with other issues. In turn, this feeds back to renewed and refined monitoring.

One of the inherent reasons for monitoring is to detect specific types of change. Usually monitoring activities are parts of much larger programmes designed to manage components, properties and processes of ecosystems for specific end purposes. Recently for living organisms and especially for natural (as opposed to cultured) populations, this end purpose usually has come to mean sustainable resource use. Description of change through adequate monitoring is insufficient in and of itself to provide the understanding necessary to achieve sustainability. Thus, along with appropriate monitoring of important properties or components of the ecosystem, relevant monitoring or acquisition of information on changes in potential causative agents must similarly be conducted. That is, as part of the context for monitoring living marine resources, information on major factors that directly and indirectly affect the resources must similarly be gathered. This could be as simple as collecting appropriate harvesting information either as numbers or biomass captured, area disturbed (e.g., by trawling) and frequency of disturbance, or by monitoring change in major physical and chemical properties. Alternatively, this could be more complex such as monitoring major potential perturbing influences such as climate change. Regardless of the scale, monitoring such impacts is essential for establishing cause and effect linkages between the impact and the living marine resource and is therefore an integral part of the monitoring-research linkage (Fig. 1.1).

1.3 LMR Monitoring as a Subset of Other Monitoring Activities

Living marine resources are only one subset of the various components and intersecting processes that constitute ecosystems. The physical and chemical environment (habitat) is a critical general group of basic components (Fig. 1.1). Although this present treatment is focussed upon LMR, fundamental value added benefit can be derived from parallel monitoring of the abiotic components of marine ecosystems and the processes which affect the living components. This is especially true for assessment of the impact of anthropogenic activities and in particular pervasive ones such as global change.

1.4 Monitoring in the Context of Scientific Research

Monitoring is an activity directed to the specific end purpose of detecting change or temporal stability in a system. Other aspects of more general science include the incorporation of observations into the general knowledge base and thus the generation of new knowledge or updating existing knowledge. Furthermore, in the western scientific ethic, fundamental observations of systems provide the empirical base for the generation of hypotheses about how things work (inductive reasoning), their testing, and refinement (deductive reasoning). The latter activities are subsumed under the general heading of research (Fig. 1.1) which is intimately linked to knowledge development.

Thus, monitoring in general and LMR monitoring in particular are subsets of a much more extensive and highly integrated system of developing and applying new knowledge.

1.5 LMR Monitoring in the Context of Dynamical Systems

Ecosystems and their biotic components are inherently dynamic. That is, they change regularly. Thus, it is important to define at the outset the detection of what type of change is being sought when monitoring. Much of the change manifested by ecosystems is usually cyclical. The clearest example of this is perhaps seasonal changes, however, cycles at other time scales is also known. The study of natural cycles is interesting in itself as a descriptive property of the ecosystem, but monitoring is not usually intended to uncover such cyclical change, especially at seasonal time scales, except perhaps to detect perturbation of those cycles. Rather, monitoring is usually intended to uncover directional change (e.g. long-term "trends") in ecosystems which may be superimposed on top of, or obscured by, regular ecosystem cycles. Discerning directional change and perturbation of cycles from regular, normal cyclical change and attributing cause to those changes are integral to proper monitoring. This is especially true for evaluating the acceptability of the change and for developing mitigative or adaptive responses to the changes. Once again, to ensure that monitoring effectively captures the required information, proper and clear definition of the goals of the monitoring programme must be developed, appropriate properties to monitor must be defined, and the monitoring must be continued for sufficient time to differentiate the desired signal (e.g., directional change) from the noise (e.g., natural cycles) in the system.

References

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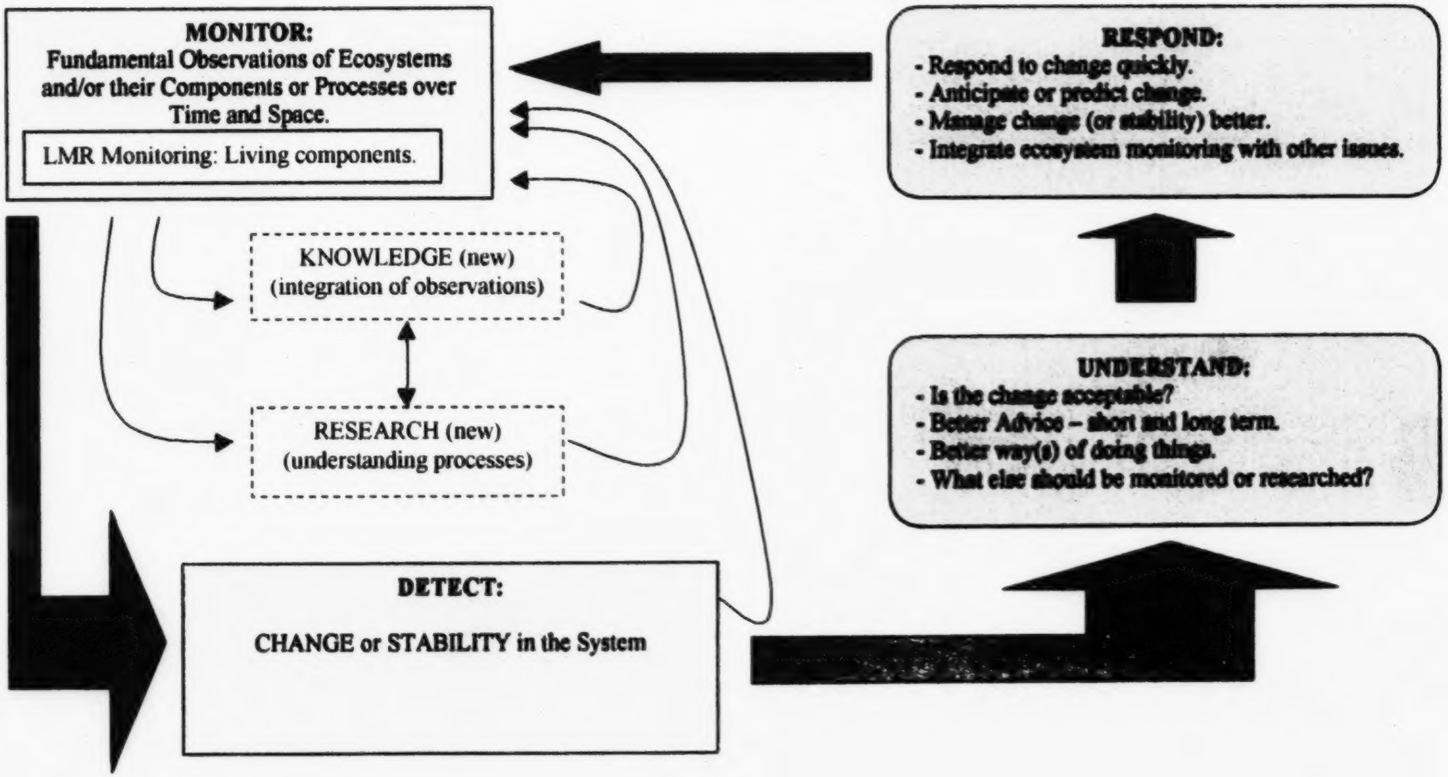
Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, N.J.

Fig. 1.1. ECOSYSTEM MONITORING as a Component of Ecosystem Stewardship – a model


MONITOR:
Fundamental Observations of Ecosystems and/or their Components or Processes over Time and Space.
LMR Monitoring: Living components.
KNOWLEDGE (new)
(integration of observations)
RESEARCH (new)
(understanding processes)
DETECT:
CHANGE or STABILITY in the System
UNDERSTAND:
- Is the change acceptable?
- Better Advice – short and long term.
- Better way(s) of doing things.
- What else should be monitored or researched?
RESPOND:
- Respond to change quickly.
- Anticipate or predict change.
- Manage change (or stability) better.
- Integrate ecosystem monitoring with other issues.

Notes:
Monitoring for ecosystem management in blocks and solid filled arrows.
Monitoring link to research and understanding in open blocks and line arrows.

2 LMR-GOOS

2.1 LMR and National Issues

In January 1999, DFO scientists from across the country met in Ottawa to draft plans for a Canadian contribution to the ocean component of GOOS. Led by members of the Ad Hoc DFO Committee on the GOOS Climate Module, the goals for the workshop were to outline present monitoring activities, identify information gaps, and begin the process of defining a program (or programs) to address both international and Canadian needs for climate observation. Although the priority task of this workshop was to develop the ocean contribution to the Climate Module of GOOS, considerable discussion was also given to the other three non-climate Modules of GOOS, namely the Health of the Oceans (HOTO) Module, the Coastal Module and the Living Marine Resources (LMR) Module.

The general goal of LMR-GOOS as defined in international planning documents is to:

provide operationally useful information on changes in the state of living marine resources and ecosystems, i.e. observational services and forecast to those concerned with the harvest, conservation and scientific investigation of living marine resources of the deep ocean and shelf seas.

In order to fulfill this goal, a comprehensive ecosystem and environmental observational program is required which identifies variables and parameters of importance for detection of changes in structure, behaviour and biodiversity, including the status of fishery resources.

The development of a Canadian LMR monitoring program should take into account the objectives of the new Canada Oceans Act and address the following questions: (1) What are the Canadian needs, i.e. what observational programs are required to characterize the varying states of our ecosystems and enable prediction of their future states? (2) What are we currently monitoring and do elements of those programs address the goals and objectives of LMR? (3) Do current monitoring programs meet Canadian needs or do they require enhancement? (4) Are the current or enhanced monitoring activities relevant to the global LMR effort? The report generated from the 1999 workshop addressed these questions only partially - the current state of LMR-relevant monitoring activities was assessed by region, provisional enhancements to existing activities were identified and critical information gaps were listed (DFO, 1999). However, what was lacking was: (1) a clear statement of Canada's *ecosystem objectives* for integrated oceans management and conservation and (2) the *indicators* by which the observational tools we employ to monitor the ocean ecosystem can be assessed. The monitoring program must provide *data products* of relevance to these indicators for the ecosystem objectives.

The 1997 Oceans Act obliges Canada to incorporate ecosystem objectives within an integrated oceans management framework. The pending legislation addressing species at risk of extinction will generate recovery plans for endangered marine species. Thus, we are in a transition period with respect to the need for scientific advice on management of ocean uses (oil and gas, aquaculture, marine transportation, eco-tourism, recreational use and fisheries). Management will continue to occur at the sectoral level, yet the aggregate activities need to meet some yet to be defined ecosystem objectives. Fisheries management needs to take into account ecosystem considerations, and other ocean uses have impacts on the ecosystems that need to be evaluated in relation both to the fisheries impacts and the broader conservation objectives inferred under new international conventions and national legislation.

The ICES/SCOR Symposium on the Ecosystem Effects of Fishing, which was held in Montpellier in March 1999, provided some guidance on a framework for the incorporation of ecosystem considerations within fisheries management. The Symposium overview paper (Gislason et al. 2000) listed six potential ecosystem objectives for oceans management, three address biodiversity and three habitat productivity. The traditional conservation objective for the target species of fisheries management is subsumed within the latter three.

Considering the ecosystem-based issues discussed above, the interest in living marine resources monitoring generated at the 1999 Climate-GOOS workshop in Ottawa, and the current discussions of ecosystem objectives at the international level, the Canadian LMR-GOOS workshop was organized to gain a broad consensus on the appropriateness of this conceptual framework for Canada in developing a national LMR monitoring program and to expand on the list of indicators that will help determine and prioritize the ecosystem features to be monitored and monitoring products generated as a consequence.

References

DFO. 1999. LMR draft report of the *ad hoc* GOOS Working Group. Workshop on Ocean Component of Canadian Climate Observing System (GCOS/GOOS), Ottawa, 28-30 January, 1999.

Gislason, H., M. Sinclair, K. Sainsbury, and R. O'Boyle. 2000. Symposium Overview: incorporating ecosystem objectives within fisheries management. ICES Journal of Marine Science, 57:468-475.

2.2 LMR International

The international LMR-GOOS panel has met formally four times in the past 3 years and made considerable progress in defining and designing the living marine resources module for GOOS. A generic operational monitoring system has been identified, as have potential products. Several pilot projects have been proposed to demonstrate the concept of living marine resources monitoring. Nine on-going monitoring systems highlighting living marine resources have been recommended by the Panel for inclusion in the GOOS Initial Observing System.

International LMR planning meetings

Meeting	Location	Date
1998		
LMR-I Drafting Mtg	Paris	August 17-19
1999		
LMR-II	Montpellier	March 16-19
LMR-III	Talcohuano	December 8-11
2000		
LMR/HOTO/C-GOOS Merger	Washington	April 17-18
LMR-IV	Honolulu	May 1-4

A draft of the LMR-GOOS strategic design plan was completed following LMR-IV in May, 2000. An important step in the development of the design plan was the use of retrospective experiments to test whether existing monitoring programs have been effective in detecting and forecasting major ecosystem changes, e.g. regime shifts. One such study, conducted for the Scotian Shelf (Sinclair et al. 1999), concluded that the monitoring programme in place was adequate to describe some aspects of the ecosystem and fishing changes (fishing patterns, fish and mammal communities, state of the ocean/atmosphere) but on its own was not sufficient to interpret causes of the major finfish collapses observed.

The retrospective experiments have guided the LMR-GOOS panel in defining the generic operational observing system which will operate on three scales: open ocean, coastal ocean and coastal/inshore, each having a distinctive suite of properties, and time and space scales of observations reflecting the inherent complexity and nature of variability of these systems. While the physical properties of interest will likely be much the same offshore and inshore, the numbers and types of biological observations will be greater inshore.

Observational requirements will fall into the following broad categories:
1. Atmospheric variables
2. Physical oceanographic variables
3. Chemical variables
4. Phytoplankton and primary productivity
5. Zooplankton (including fish eggs, fish and invertebrate larvae)
6. Benthos
7. Pelagic forage species
8. Commercial finfish and invertebrates
9. Top predators (including planktivorous cetaceans)

In accordance with the framework for implementation of GOOS (IOC, 1998) within two themes based on physical domain; (1) coastal and shelf monitoring and modelling and (2) global open-ocean monitoring and modelling, the chairs of the three non-climate modules of GOOS (C-GOOS, HOTO, LMR) met in April, 2000 to discuss and develop guidelines for the merger of the three into a single panel. The integrated Coastal Ocean Observations Panel (COOP) representing theme 1 will be the analog to the Ocean Observations Panel for Climate (OOPC) for theme 2. The goals of COOP are to monitor, assess and predict effects of natural variations and human activities on the marine environment and ecosystems of the coastal ocean, including issues of ecosystem health, living marine resources, natural hazards and safe/efficient marine operations. Although the emphasis will be on coastal ecosystems (estuaries, bays, sounds, fjords, continental shelves), boundaries will be scaled by the problems addressed and the products produced. The scope, terms of reference, initial foci, operationalisation and membership of COOP will be developed by the end of 2000 and the COOP implementation plan completed in by 2002.

References

IOC. 1998. The Global Ocean Observing System – Propectus 1998. GOOS Publication No. 42.

Sinclair, M., R. O'Boyle, L. Burke, and S. D'Entrement. 1999. Incorporating ecosystem objectives within fisheries management plans in the Maritimes region of Atlantic Canada. ICES CM 1999/Z:03.

3 Definition of Approach

3.1 Elements

The general approach to monitoring living marine resources within a global ocean observing system contains four essential elements:

1) Recognition that a central goal of an observing system is to detect "changes" in the state of the system, and to detect these changes rapidly. Ecosystems are dynamic, such that they undergo changes routinely on a variety of time scales (e.g. seasonal changes), but they also show stability, so that particular marine ecosystems are often described as "cod" or "crab and shrimp" systems, etc. It is usually this latter property ("stability") that is of major concern when the system appears to suddenly shift from one stable state to another. It is these types of changes that need to be detected quickly.

2) An understanding (definition) of the spatial domain being monitored, which in some sense is representative of the ecosystem. These spatial domains may be set for practical reasons, such as jurisdictional boundaries, or they may be set for habitat or species distributional reasons. However they are defined, there is usually at least an implicit sense of the spatial domain being represented by the monitoring program. One of the early research requirements of the program is to establish the spatial (and temporal) scales over which particular observations are representative.

3) Definition of indices and products. These are what are usually considered as the outcomes from monitoring programs, e.g. the hydrographic conditions at a particular time and place, or the abundance of a particular species of fish. They are also clearly related to the time and space scales of the underlying processes that they represent. The particular choice of what to monitor, the indices that result, and the products that are produced are crucial to the long-term success of a monitoring program.

4) Establishment of a data management strategy. Without an explicit and formal system (with timelines) for analysing observations and submitting data to a central storage system, the monitoring program will bog down and collapse. Rapid detection of

"change" requires rapid availability of the data. Any long-term program also needs strong institutional support for it to continue; this support can be best assured through rapid data availability and accessibility by a broad user community – i.e. broader than those conducting the monitoring program.

3.2 National Approach

Canada continues its support of GOOS as the principal international mechanism for obtaining long-term systematic observations of the marine environment, both regionally and globally, to meet a broad range of user requirements. In the past, this support has primarily involved Canadian participation in the planning of GOOS through its panels, working groups, and I-GOOS, as well as through Canada's support of the infrastructure that is being used to implement GOOS. In the future, however, Canada will contribute more directly to GOOS through the designation of parts of its long-term monitoring effort as contributions to GOOS and do so in a manner that is consistent with the GOOS Principles.

Within Canada, the responsibility for the planning and implementation of ocean observing systems rests primarily with the Department of Fisheries and Oceans (DFO). Collaborations are established with other departments and agencies to include those variables for which the responsibility falls outside DFO. Within this framework, ocean monitoring programs have been (or are being) developed for the ocean off both the Atlantic and Pacific coasts and to a lesser extent for the Arctic. These programs have been designed to meet various Canadian requirements for marine environmental information and have elements that encompass C-GOOS, LMR and HOTO elements. Some elements are presently being routinely carried out as part of existing monitoring and research programs.

Under the 'Canada Oceans Act', Canada has placed considerable emphasis in developing coastal zone management strategies and designating various ecologically sensitive areas as 'Marine Protected Areas'. Furthermore, Canada does have operational programs in these areas, especially as they relate to fisheries, fish habitat and overall marine environmental quality. In an effort to evaluate the effectiveness of current monitoring programs in meeting Canada's ecosystem objectives for integrated oceans management and conservation a number of national workshops have been held or proposed.

At issue with regard to living marine resources is the question of whether conventional conservation strategies, principally directed to harvest fisheries resources and specifically to single species, achieve broader ecosystem objectives taking into account multiple ocean resources uses and activities? This question was a major focus at the ICES/SCOR Symposium on the Ecosystem Effects of Fishing in Montpellier, France in 1999. The ICES Working Group on Ecosystem Effects of Fishing Activities (WGECO) phrased the question as follows (p. 215, ICES 1999):

"If all fisheries were managed so that there was a high probability of achieving conservation objectives for the target fish stocks, would there be a high likelihood of achieving conservation objectives for ecosystems?"

WGECO concluded that the answer to this question was "NO" for a number of reasons:

- genetic diversity of target species at risk
- by-catch species at risk
- dependant species at risk
- increase in scavengers may place some species at risk

There appeared to be broad consensus at the ICES/SCOR Symposium, that the present approach to achieving conservation objectives of fisheries activities, even if successfully implemented, would not achieve yet to be defined ecosystem objectives. There was not, however, consensus amongst scientists on what additional restrictions are required, nor on what features of ecosystems need to be protected.

The approach introduced by Canadian representatives at the Montpellier meeting is to add ecosystem objectives to the conservation component of each of the single species fisheries management plans, as well as to the management plans of other ocean use sectors. Then the aggregate activities would need to be evaluated at a range of geographic scales.

4 Ecosystem Objectives

The 1992 Convention for Biological Diversity (CBD), the Straddling Stocks Convention (UNFA), and the Code of Conduct for Responsible Fishing have generated broader conservation objectives for the management of ocean use activities. The 1997 Oceans Act obliges Canada to incorporate ecosystem objectives within an integrated oceans management framework. The pending legislation addressing species at risk of extinction will generate recovery plans for endangered marine species. Thus we are in a transition period with respect to the need for scientific advice on management of ocean uses (oil and gas, aquaculture, marine transportation, eco-tourism, recreational use and fisheries). Management will continue to occur at the sectoral level, yet the aggregate activities need to meet some yet to be defined ecosystem objectives. The scientific advisory context for LMR-GOOS is in transition. Fisheries management needs to take into account ecosystem considerations, and other ocean uses have impacts on the ecosystems that need to be evaluated in relation both to the fisheries impacts and the broader conservation objectives inferred under new international conventions and national legislation.

The ICES/SCOR Symposium on the Ecosystem Effects of Fishing, which was held in Montpellier in March 1999, provided some guidance on a framework for the incorporation of ecosystem considerations within fisheries management. The Symposium overview paper (Gislason et al. 2000) lists six potential ecosystem objectives for oceans management, three address biodiversity and three habitat productivity. The traditional conservation objective for the target species of fisheries management is subsumed within the latter three. For each objective there will be a need to define indicators of relevance as well as reference points that trigger management action. The objectives, as well as a provisional list of indicators and reference points presented at the Montpellier symposium are:

Examples of Ecosystem Objectives, Indicators and Reference Points for Ocean Management Areas (OMAs)

Objectives	Indicator	Reference Points
Maintenance* of ecosystem diversity	Areas of the continental shelf disturbed by fishing activities	Percentage of each habitat type that is undisturbed
Maintenance of species diversity	• Number of individuals of the species at risk • Geographic area of distribution	• Maximum by-catch annually • Percentage of distributional area relative to period of moderate abundance
Maintenance of genetic variability within species	• Number of spawning populations of targeted species • Selection differentials	• Percentage reduction in spawning areas • Minimum selection differential
Maintenance of directly impacted species	• Fishing mortality • Spawning stock biomass • Area of distribution	• $F_{0.1}$ • Minimum stock biomass necessary for recruitment and forage • Percentage of distribution relative to period of moderate abundance
Maintenance of ecologically dependent species	• Abundance of key predator • Condition of key predator • Percentage of prey species in diet of predator	• Minimum abundance level of predator • Minimum condition level of predator • Minimum percentage in diet of predator
Maintenance of trophic level balance	• Slope of size spectrum • Pauly's FIB index • Aggregate annual removals by fishing for each trophic level	• Minimum slope • Minimum level for index • Maximum percentage removal from a trophic level

*Some discussion was generated at the BIO workshop on the appropriateness of the term "maintenance" with regarding to meeting ecosystem objectives. The suggestion was made that "observe" may be more realistic. The issue was not resolved.

5 Indicators

For each objective there will be a need to define indicators of relevance as well as reference points that trigger management action. Indicators should have three key attributes: they should be measurable, interpretable and sensitive to changes in biotic or environmental change (see Sections 8.3.4.1 and 8.3.6.1). At the Canadian LMR-GOOS workshop at the Bedford Institute of Oceanography (BIO) there was a detailed review and discussion of indicators for each of the six objectives introduced at the Montpellier symposium on Ecosystem Effects of Fishing. To the degree that a region wants to achieve a particular objective, LMR-GOOS for that ocean area needs to monitor properties that will generate data products on the respective indicators. Detailed discussion of indicators can be found in the rapporteur reports and appendices that follow. Among the indicators proposed at the BIO workshop were:

Maintenance of Ecosystem Diversity

The benthos is considered separately from the pelagic component of the marine biota. Due to recent advances in multi-beam and side-scan sonar it is now possible to routinely map the bottom sediment type and relate this to the number and geographic pattern of bottom communities in 'benthic ecosystems' that need to be maintained. The indicators to be monitored are:

- the spatial extent of disturbance (by fish gears, oil/gas operations, aquaculture sites, etc.) for each category of benthic habitat in the classification scheme, and
- benthic community properties in 'no disturbance' areas (e.g., MPAs) and disturbed areas for each benthic ecosystem type.

For this objective it is assumed for planning purposes that some percentage of each habitat type would need to be undisturbed.

For the pelagic component of the biota the geographic scale of ecosystems/communities is much larger, e.g. Longhurst (1998) areas for plankton. The indicators would be:

- measures of geographic patterns in plankton and fish community structure.

The present monitoring activities in the Atlantic (CPR line, seasonal zooplankton net hauls on transects from AZMP, ecosystem trawl survey from Cape Hatteras to Cape Chidley) should be sufficient to generate the data products.

Maintenance of Species Diversity

The minimum required for this objective is to provide indicators for the recovery plans of the species at risk of extinction. The indicators need to be considered at the geographic scale of evolutionary significant units (ESUs), and are species specific. They include:

- Rate of population decline (decline in abundance and absolute population size, abundance fluctuations),
- Contraction in distributional area (extent of occurrence, area of occupation),
- Number of spawning components (population fragmentation),
- Number of individuals and effective population size (Ne)

- Other population and individual characteristics (No. of mature individuals, age of maturity, rarity, growth rate, fecundity, recruitment rate),
- 'Integrity' of essential habitat
- By-catch, or mortalities

Maintenance of Genetic Variability within Species

The indicators for this objective have some overlap with that above, but need to be considered for a much wider range of species, in particular for species that are commercially exploited. There are at least two high profile concerns, the loss of spawning components and the reduction in genetic variability within populations (both due predominantly to fishing practices). The indicators include:

- Census (total population size) and effective population size (Ne) per generation,
- Number of populations,
- No. of progeny per parent,
- Sex ratio
- Selection differential for life history parameters such as size-at-age and age-at-maturity,
- Mutation and gene flow,
- Evolvability,
- Co-evolution,
- Nearest neighbor estimates for sessile invertebrates

Maintenance of Exploited Species

This objective subsumes the need to prevent growth and recruitment overfishing of the commercial species targeted. The traditional indicators would be:

Surveys-based
- Stock size (inc. spawning stock biomass, B),
- Exploitation rate (fishing mortality, F),
- Recruitment to stock.

Recently there has been a move to broaden the scope of the indicators to include such measures as:

Biological
- Size/age composition of population,
- Growth of target spp.,
- Condition of target spp.,
- Areal distribution of stock,
- Stock reproductive potential.

Environmental/ecological
- Predator (on target spp.) abundance,
- Prey (of target spp.) abundance.

Fishery

- Spatial distribution of catches,
- Fishing effort/trends in catch per unit effort,
- Amount and fate of bycatch,
- Discards by spp.,
- Recent trends in biomass and recruitment,
- Compliance of fishers.

With the use of a broader range of indicators a qualitative step-light approach (green/yellow/red ratings by indicator) is envisioned, which would complement the present use of quantitative assessment models.

Maintenance of Non-exploited Species

This objective addresses the importance of food-chain interactions amongst the target species of commercial fisheries and the key predators on such species. It is of particular interest for fisheries on forage species such as krill and small pelagics. CAMLLAR has been a leader on how to deal with this ecosystem consideration. There are two approaches. The first was the traditional indicator for the target species (F and B), but takes into consideration that a larger biomass should be sustained than is the case under traditional fisheries management approaches. In essence the reference point for biomass of the target species changes, but the indicators stay the same. The second approach includes the monitoring of key predators of the targeted forage species under commercial exploitation. Indicators could include:

- Abundance of key predation of exploited,
- Condition of key predator,
- Percentage of prey species in diet of predator.

Maintenance of Emergent Ecosystem Properties

This class of objectives addresses emergent properties of ecosystems, and is somewhat controversial. There is a need to monitor properties of marine biological communities that are indicators of their structure and function, even though at this time there is not a consensus on optional states of trophic level balance. Indicators would include:

- Indices of diversity (richness, evenness, dominance),
- Slope of size (No. or biomass) spectra, k-dominance curves, ABC curves,
- Pauley's FIB index,
- Aggregate removals by fishing at each trophic level.

Additions to Present Monitoring Activities

The Canadian LMR-GOOS workshop indicated a need to augment present monitoring activities if the broader ecosystem objectives are a component of an integrated ocean observational program. The additions would include:

- Bottom areas disturbed by ocean use activities,
- Benthic community monitoring in disturbed and undisturbed areas by habitat type,
- Targeted surveys for species-at-risk,
- By-catch of species-at-risk and other mortalities due to human activities,
- Numbers and locations of spawning populations for exploited species,
- Selection differentials for certain exploited species,
- Sex ratio of exploited species,
- Condition, abundance and food habits of selected key predators on forage species.

Research Needs in Support of Monitoring

A key challenge in the transition to integrated management of ocean uses is the need to assign *causality* to observed charges in marine ecosystems. If a change is observed in an indicator will we be able to associate that change with natural environmental variability or impacts of a particular ocean industry (e.g. oil/gas, aquaculture, fishing). Thus it is essential to monitor a broader suite of oceanographic and atmospheric indicators that allow description of natural climate variability and modeling of impacts.

References

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6 Workshop Presentations and Discussion

6.1 Objective #1 Ecosystem Diversity (P. Pepin, Rapporteur)

Background

Don Gordon outlined requirements of observation systems from a personal perspective based on analysis of benthic populations. Although there were some concerns about the narrow perspective presented, the principles and goals outlined during the presentation can be applied to all aspects of the marine system, including the incorporation of the pelagic community.

The primary goals Don identified with this objective are to identify the types of distinct habitats on which diverse species depend; try to maintain these different types of ecosystems; and within these, maintain the diversity of species mix, functional groups, age and size structure.

The principles outlined during the presentation assume that the underlying objectives defined by our clients include: biodiversity, productivity and stability. Management/responses must allow multiple uses where some areas are altered whereas others are protected.

The interpretation of any observations of change require that we understand the natural underlying variability of the systems we hope to observe.

To achieve this skill, Scientific Advisory Bodies need to:

- Classify and map benthic habitat and communities,

- Know long term temporal trends over a diversity of areas/communities (undisturbed),
- Map spatial extent of disturbance,
- Monitor at disturbed sites.

Discussion

In answer to the relative contribution of remote sensing versus traditional sampling, Don indicated that remote sensing serves as a first step but that traditional sampling is still required to measure changes in the biological community. Remote sensing tools provide a characterization of the physical habitat, which are correlated/associated with certain types of communities. Sampling is still needed but maybe to a lesser degree. There is still significant research and development to be undertaken – the tools are at hand but the interpretation and interrelationship still have to be developed.

Much of the work to be done before we can proceed to understanding the underlying variability involves basic description of the complexity of the environment. The underlying temporal variation of some groups can be assessed more readily than others because they can be surveyed more easily (e.g. large or commercial species that are on the surface).

One of the underlying problems facing the development/amassment of this information is the need to share data. Many industrial partners have information that is considered proprietary but their importance to the public good is fundamental – the issue still has to be resolved.

It is essential to recognize the issues of scale related to the description and monitoring of ecosystem diversity. Ecosystems are made up of several habitats but a habitat does not represent the former. Different species use different habitats during different stages of development. The key in monitoring is to establish the diversity of habitats within a system and identify the observation needs to assure that change can be detected throughout the components of the system.

When asked about identifying key components for long-term monitoring capability and feasibility, Don identified the need for broad surveys (which deals with larger species and functional groups) with a few key sites that could be investigated in greater detail (but at relatively greater cost). The level and degree of detail to be identified depends greatly on understanding a range of scales and knowing the sensitivity of different organisms to perturbations (anthropogenic or environmental).

There was discussion about the lack of information on links between pelagic and benthic ecosystems, and the lack of discussion at this workshop about issues concerning diversity of pelagic ecosystems.

Indicators of large ecosystem change respond more rapidly in pelagic systems than in benthic systems. Consideration of different levels of stability and resilience in the interpretation of observations is required. Therein, the structure of the different communities (pelagic and benthic) represent elements than should be described as part of any ecosystem monitoring activities.

The spatial structure of ecosystems, and their variability, are key elements in the design of any monitoring activities – gross scale observations allow the scientific community to pick key sites (e.g., sediment types give the big picture; structure within types provides the observations on which to concentrate effort).

6.2 Objective #2 Species Diversity (J. Reist, Rapporteur)

Background

What is it? - Species diversity is a complex concept that has occupied biologists since the time of Linneaus who first formulated fundamental scientific rules for the naming of species in 1758. Organisms differ at many levels of organization, from the individual to various groupings of individuals. One of the most fundamental natural groupings is that of the biological population (see below). Species are aggregations of biological populations that share great similarity, commonality of evolutionary descent, and the individuals of which are capable of freely reproducing if they were to be brought together. As assessed by taxonomists, small differences between populations are typically used to assign membership to the same species, whereas larger differences may be sufficient to assign membership to different species. The existence of different species allows for the assessment of diversity of species (e.g., simply the number of distinct species present in any group of organisms). The simplicity of this definition belies the complexity of trying to actually measure species diversity (see below).

Species can be viewed from many different perspectives – taxonomically (e.g., the number of closely related species in a specific higher group, area or ecosystem) through to functionally (e.g., the roles performed in ecosystems processes and/or biotic interactions). The former perspective addresses the evolutionary integrity of species diversity whereas the latter addresses the importance of this diversity in maintaining healthy sustainable ecosystems. Thus, understanding species diversity, monitoring it, and addressing management actions to conserve it, must include both functional and taxonomic components (Huston et al., 1999).

An often overlooked aspect of both taxonomic and functional diversity of species is that of diversity between the species level and the level of the biological populations. That is, careful examination of variety within species often reveals the presence of diversity that can in some senses be considered taxonomic but often is driven by functional constraints impinging on the biology and life history of the species. For example, fish populations often exhibit differently adapted generalised sub-groups. Such sub-groups are perhaps best known for anadromous fish such as Arctic char (*Salvelinus alpinus*) or Pacific Salmon (*Oncorhychus* spp.) which exhibit both anadromous (i.e., sea-going) and lake-dwelling or river-dwelling (i.e., freshwater) life history forms. In the case of chars and some salmon, these can be exhibited both as distinct populations (e.g., lake-dwelling and anadromous) and/or distinct life history types within populations (e.g., anadromous and residual forms). Similar diversity likely exists for marine fish (e.g., perhaps inshore and offshore cod) as well as other key components of marine ecosystems (e.g., benthos and plankton) but far less work has been conducted to describe and understand this. These forms may co-occur during parts of their life history, over evolutionary time they may transition from one to the other, and the functional relationships of one to the other in maintaining species' integrity and adaptability are unknown but likely extremely important to long-term persistence of the species. Thus, it is important to note that the fundamental basic description of the diversity within a species is as much an absolute pre-requisite for any monitoring programme aimed to manage aquatic marine ecosystems, as is description of diversity between species.

Why is it important? - Taxonomic and functional diversity at and immediately below the level of the species is important to the structure and function of the ecosystem in a number of ways. (1) It is a basic and easily measured index of diversity (but see below). (2) Also, ecosystem functions are believed to improve with increasing diversity, trophic structure is an important derived ecosystem property of species diversity, productivity is intimately related to the nature and diversity of species present in the ecosystem, and other aspects of a functional ecosystem (e.g., physical and chemical properties, successional processes, and dynamics of contained populations) all are affected by taxonomic and functional diversity of species in an ecosystem (see Huston et al., 1999 and references therein). All of these properties of species-level diversity contribute to the stability and resilience of ecosystems (Huston et al., 1999), which in turn buffers the ecosystem to the effects of both natural and anthropogenic impacts. Therefore, monitoring and preservation of biodiversity at the species level is integral to ecosystem conservation and the maintenance of ecosystem integrity.

How to monitor it? - The decision of how to monitor species diversity for living marine resources rests in part with the overall objectives of the monitoring programme itself, which as noted previously (Sections 1.1-1.5) must be clearly defined a priori. In addition, an initial decision must also be made whether to monitor species diversity in terms of taxa, functionality, or both. The basic measure of biodiversity is the number of different types of the units of relevance (taxa, functional types, populations, genes, etc.). Species richness (number of species in an area) along with relative abundance measures for taxa in an ecosystem are the subject of a large literature and various quantitative indices have been developed (e.g., Shannon-Weaver) (see Magurran, 1988, other references in Huston et al., 1999 and Section 8.3.6.1 below), almost all of which have various utility, applicability and shortcomings. From the functional perspective, two relevant levels can be identified: (a) Functional Types – the number of functions performed by identifiable groups of species; and, (b) Number of Functional Species within each type (Huston et al. 1999). It is not the aim to review the various approaches herein; rather, the focus is upon salient features of species-level monitoring which are common to both these approaches. Regardless of the method used, it must of necessity be repeated over time to provide the information on change required by the monitoring programme.

Key to describing, understanding and thus monitoring patterns of biodiversity is the spatial scale defined as relevant, and regularities in distribution of the taxa or functional types across that space. Regularity of organisms in relation to their environment results in predictability in diversity (Huston et al., 1999) which in turn aids in planning and executing monitoring programmes. Thus, the key patterns of biodiversity at the species level must be adequately described as an initial step in the monitoring programme. Various scales of species diversity can be delimited from that of the local habitat (alpha diversity), through that between habitats (beta diversity), to regional scales (gamma diversity). Definition of appropriate spatial scale, and repeated adherence to this definition over time is required to adequately monitor species diversity.

To determine how to monitor species diversity it is also relevant to consider aspects of the species themselves which may place them at greater risk of extirpation or extinction (Musick, 1999 and Huston et al., 1999). These factors include: a) rarity due to low abundance or elusiveness; b) small geographic range and/or endemism; c) specialized habitats and/or need for and transition between multiple habitats to successfully conduct life history (e.g., anadromous fish); d) aspects of biology, which for fish may include iteroparity, long lives and late maturity, low fecundity, and infrequent natural recruitment (e.g., so-called 'K'-selected species which have limited capacity for compensation); e) mutualism (i.e., strict inter-dependencies between species; f) strict and narrow niche requirements (e.g., narrow thermal tolerances); g) productivity and survival; and, h) position in the trophic structure of an ecosystem in relationship to the complexity of that trophic structure.

Establishing and monitoring species diversity can be conducted in a number of ways. Existing information as geographical, spatial and/or temporal distributions constitutes the most basic form of species diversity for taxa of interest. If habitat associations of biota are both known and relatively narrow, habitat mapping can be used as an indirect measure of the potential presence of a species (or a suite of regularly co-occurring species). However, both of these approaches are not good substitutes for site-specific information gathered through appropriately designed, directed surveys (Huston et al., 1999). At specific locations, species vary with respect to their abundance being either common or rare. Information on rare species is often (or will be) relevant from a regulatory perspective whereas that on common species is usually more useful for monitoring and management of the ecosystems. Appropriate systematic sampling can be used to gather the necessary data and there is a significant body of literature available regarding the design, execution and analysis of such sampling programmes.

Recognition of fundamental ecosystem properties is essential to the design of adequate surveys and the development of appropriate monitoring programmes for living marine resources. One substantive property of ecosystems is that different areas of the ecosystem have different comparative advantages. That is, specific combinations of physical, chemical and biological components found in specific parts of the ecosystem provide for particular ecosystem functions (Huston et al., 1999). Thus, heterogeneity is to be expected across the ecosystem. From the perspective of species biodiversity, this means that no single location is ideal for all species. This has two consequences: (1) sampling programmes to assess biodiversity must be designed to sample all relevant areas of the ecosystem, and, (2) specific locations within the ecosystem may be areas of high inherent biodiversity. Such areas are often colloquially referred to as 'biological hot spots'; examples include perennial open water areas in the arctic marine environment (i.e., polynyas). Because of their obvious high biodiversity such hot spots are often the focus of regular scientific investigation. However, using an analogy from plant biodiversity, highly productive areas are often devoted to regular harvesting or monoculture and thus low in biodiversity. In comparison, areas of inherent low productivity are usually less 'managed' and have high inherent species biodiversity. For living marine resources, the analogy to trawlable areas versus non-trawlable areas for example is obvious and serious attempts to establish and monitor species diversity need to examine the range of such habitats within the ecosystem. Also, the intensity of sampling must be considered to ensure representation of all species present in that particular ecosystem.

Cross linkages between species diversity and other concepts - The concept of species diversity and monitoring changes in it in natural populations has a number of relevant linkages to other issues:

Human Impacts - In monitoring biodiversity at the species level, aspects of human impacts on the system must also be considered. This is especially true for mixed fisheries especially if K-selected species are an incidental by-catch, i.e. they are not targeted and thus not likely to be regulated or monitored in a comprehensive way (Musick, 1999). Such species have limited capacity for compensation after severe population declines. Discretion must be exercised in assessing the relevance of particular impacts on species diversity and programmes to monitor it. For example, not all disturbance is bad, e.g. natural events such as fire re-set the successional processes in terrestrial ecosystems thereby increasing local species biodiversity. In some cases, habitat alteration by fishing practices (e.g. trawling) as well as the act of exploitation of the fish population itself may re-set marine successional processes and, at low levels, may actually be beneficial in increasing local species biodiversity. However, obviously at some point such activities become detrimental to biodiversity. Impacts of human alteration of aquatic systems are known to increase the incidence of hybridization in fish that may be a useful tool for assessing the relative level of impacts in some systems. Similarly, impacts disrupt normal developmental processes in fish thus leading to physical anomalies and/or lateral assymmetry in body parts. Such assessment may also prove useful in assessing relative levels of impacts.

Criteria to identify risk – The obvious ultimate impact on species diversity is to reduce it through local or global extinction of biota. Criteria to identify the varying degrees of risk of impact, local extirpation, and global extinction are key in assessing effects on species diversity. Such criteria include declining population sizes as well as rates of decline in key productivity parameters (e.g., intrinsic rate of increase, von Bertalanffy k, fecundity, age-at-maturity, maximum age, etc.) (Musick, 1999). Interconnections between species and habitat diversity were noted above, and habitat impacts can exacerbate other impacts impinging on species diversity.

Evolutionarily Significant Units – As noted above, species are composed of numerous biological populations, each of which is reproductively isolated to some degree and which exhibits a unique suite of characteristics such as abundance and various vital rates. Thus, each population within a species will have a different level of vulnerability to impacts. Furthermore, the local habitats affect vulnerability, e.g. colder environments decrease productivity which increases vulnerability. The result is that not all communities (i.e. local ecosystems) of organisms will operate similarly across the entire range of particular species. We must deal with dynamic communities that have multiple equilibria. From the perspective of monitoring of species-level biodiversity, these observations have implications with respect to the basic units of conservation one uses. The fact that some populations may be only marginally different from others and thus of lower overall significance than ones which are distinctly different has led to the development of the concept of the Evolutionarily Significant Unit (ESU). Such units are distinct sub-sets of the overall species which are substantially reproductively isolated from other such units and which are an important component of the overall evolutionary legacy of the species. ECUs represent important portions of the species that must be monitored and conserved.

Life History – For a monitoring programme directed towards species diversity, monitoring of long-lived species offers certain advantages. For example, if they are rare, their disappearance from the species inventory may represent significant changes to the ecosystem. Aspects of long-lived species may also be useful in monitoring specific impacts, e.g. particular contaminants accumulate in the individual over time and are sequestered in body structures (e.g. otoliths of fish). Once deposited, trace contaminants, isotopes of stable elements, and environment-specific elements which substitute for calcium in the otolith matrix (e.g. strontium), all are not remobilized during life history. Thus, these preserve a historical record of the individual's life history, the environments occupied, and contaminants encountered throughout the fish's life. Monitoring specific aspects of long-lived individuals can thus provide substantial detail regarding change not only in the species but also as proxies for change in the environment itself.

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6.3 Objective #3 Genetic Diversity Within Species (J. Reist, Rapporteur)

Background

What is it? - Genetic diversity is the variation existing in the genome of individuals (primarily encapsulated in nuclear DNA but also present as DNA associated with some organelles, e.g., mitochondria in animals and chloroplasts in plants). The genetic information forms the foundation for the biological traits and processes of the individual that sustain life. Specific portions of DNA which are homologous (i.e. the same) across individuals are referred to as genes. All individuals (except identical twins and clones) are genetically different from one another, and these differences are manifested as different linear sequences of the DNA molecule which produce different biochemical products. Different variants of genes are referred to as alleles. It is the variation of alleles between individuals that is referred to as genetic diversity.

From a taxonomic perspective, we know that individuals can be organized into distinct biological populations (or stocks). Stocks are: groups of individuals which primarily interbreed together, primarily do not interbreed with individuals from other stocks, and are usually distinguishable from other such groups by some aspect of biology (e.g., reproduce in different locations, at different times, and typically have different biological properties such as abundance, growth rate, etc.). Taxonomically, many biological populations usually make up a species (see Section 6.2 above). Taxa that do not share most descriptive traits, do not have a common evolutionary heritage, and that can not reproduce together are considered as distinct species. Because of this inherent hierarchical organization, we must consider two levels of genetic diversity – that within populations and that between populations of the same species. Thus, the presence and/or the frequency of alternative alleles constitute the fundamental level of genetic diversity both within and between biological populations.

Why is it important? - Genetic information provides the fundamental ability for the individuals to survive in their environment. In the context of the specific environments occupied by the individual during its life, specific alleles can be viewed as being relatively beneficial or deleterious. That is, differential survival or reproduction occurs among individuals and between populations through the process of natural selection. Selection which favours particular alleles promotes an increase in frequency of those alleles in the population, whereas selection against an allele will promote a decrease in frequency or the loss of that allele in the population over time. It is important to note that beneficial and negative aspects of particular alleles are tied to the environments occupied – what is beneficial under one set of environmental conditions may be less so under another set. Thus, it is a fundamental tenet of evolutionary biology that genetic diversity allows for adaptation to changing environments. Such adaptation promotes the continued existence and good health of the populations in particular and the species as a whole. Because the environments occupied by organisms are constantly changing through natural and anthropogenic causes, it follows that high levels of genetic diversity and adaptive ability are critical to maintain both within and between populations to allow for the populations to persist in highly variable and/or changing environments.

How to monitor genetic diversity? - Rapid technological innovation in recent years allows us to directly observe the genetic variation present in natural populations as well as to indirectly observe the results of that variation (as either products derived from the information in the genome or as traits of the individual). That is, the actual genetic information in the form of sequences of different building blocks (called nucleotide bases) along the DNA molecule can be determined. Additionally, variation in the biochemical products derived from the genetic information (e.g., specific proteins necessary for life functions) can be determined. Thus, genetic variability can be measured as frequencies of alternative alleles within and between populations. This can be conducted for many portions of the genome (i.e., different genes) to yield overall measures of genetic diversity. Although many ways of expressing such diversity are possible, the most fundamental is in the form of numbers of alternative alleles for specific genes. This is referred to as heterozygosity. Thus, a monitoring programme to directly assess shifts in genetic diversity must measure levels of heterozygosity within and between the populations of interest. This can be achieved by: (a) establishing the fundamental population structure of the species of interest using genetic methods; (b) regular temporal sampling of individuals from the population(s) to assess genetic diversity; (c) proper genetic testing (e.g., standardized suite of genes examined); and, (d) proper analysis of the data (e.g., allele diversity, heterozygosity measures, etc.). Such assessment must be conducted for at least one reference population of each species of interest in the ecosystem. Alternatively, assuming ecosystem linkages between species are well known, an indicator species may be useful as a proxy for assessing shifts in genetic variation across a range of species within an ecosystem.

Alternative indirect monitoring of genetic diversity among populations (but not within populations) may also be accomplishable by monitoring the number of spawning populations as well as the absolute abundances of particular species within an ecosystem. This approach will give general information regarding the overall health (as measured by numbers and abundances) of the populations. However, an indirect approach is not very sensitive to change thus will not provide direct measures of genetic diversity which will likely be the first harbingers of significant change within the populations.

Monitoring genetic diversity of several populations for each of many species within an ecosystem is a large task that may not be achievable for any but the most important ecosystems. Thus, the best approach might be a combination of general indirect assessment of number of spawning populations as well as the direct genetic assessment of a specific index population(s) of particular interest.

Benchmarks of genetic diversity – In general, there is no way to know a priori what the best levels of genetic diversity should be, other than the general idea that more is better. Thus, any monitoring approach that includes genetic diversity must establish some initial benchmarks or reference points through a programme of initial observation. From a theoretical perspective almost all the potential parameters used to assess genetic diversity have relevant reference points (see Section 8.3.3.4).

Important cross linkages between genetic diversity and other concepts - The concept of genetic diversity and monitoring changes in it in natural populations has a number of relevant linkages to other issues:

Population Abundance - Genetic diversity is inherently associated with the size or abundance of the populations. Both empirically and theoretically, smaller populations generally have lower levels of genetic diversity than do larger populations. This has several advantages useful in a monitoring context. In a situation where all other things are equal, a low level of genetic diversity can be taken as prima facie evidence of either low abundance (in comparison to other populations) or a decline in abundance (in comparison to previously known levels of diversity) of a particular population. Conversely, provided certain theoretical assumptions are met, specific measures of genetic diversity can be used to calculate what is called the 'effective population size' of a specific population – that is, the number of reproductive individuals present at a given time. This concept can in turn be used as a meta-datum to monitor change in abundance, for determination of risk of extinction, and for assigning species' status.

Evolutionary Implications – Genetic diversity provides information on historical evolutionary events that may have affected the population in the past or over the period of monitoring. All genetic diversity arises from the basic process of mutation in which specific bases on the DNA are replaced by alternate bases. This fundamental genetic variation is subsequently sorted and re-distributed by several evolutionary processes. These include the concepts of: genetic bottlenecking (i.e. severe reduction in population abundance, loss of most of the alleles, and subsequent increase in abundance but without an accompanying increase in allelic diversity); genetic drift (i.e. shift in allelic diversity over time due to fixation of alleles in small populations); and, founder effect (i.e. random sorting of alleles in small populations which newly colonize a particular area or habitat). The final major evolutionary process is selection (i.e. the favouring of a specific allele over alternative alleles at a specific gene due to effects of the environment such as predators, reproductive ability, etc.).

Population Structuring – Genetic diversity when found to be logically organized around some environmental parameter such as specific reproductive groups or locations provides fundamental information regarding the structuring of the species into discrete units (i.e., genetic stocks) which represent biological populations (see above). Such information can be used to establish geographic boundaries for stocks, migration and mixing of stocks, individual stock contribution to mixed groups, and, realized rates of immigration or emmigration between stocks. Aspects of within-population genetic diversity can also be used for purposes of forensic identification both to species and also population. It also must be emphasized that in order for any monitoring programme for genetic diversity to be successful, the appropriate pre-knowledge of population structuring and genetic variability must be established to a reasonable degree of completeness (i.e., all possible populations included).

Quantitative Genetics – Quantitative genetics is a distinct discipline from the genetic variability of natural populations discussed above. Quantitative genetics was developed in order to assess the levels of genetic basis to expressed phenotypic traits. Typically quantitative genetics is used in animal husbandry in order to understand and artificially select for desired traits. Quantitative genetics differs in a major aspect from the assessment of natural genetic diversity in that it is concerned primarily with the expressed phenotypic trait and the underlying genetic component to it rather than with specifically associating the measured genetic variation with particular alleles or genes. Furthermore, parameters relevant to quantitative genetics can only be properly established through appropriate breeding experiments. Having said that, aspects of quantitative genetics may have relevance in a monitoring programme directed to natural systems. Specifically, anthropogenic activities such as exploitation are inherently selective in their approach (e.g. fishers typically select for the largest sized fish). Over time such selection may result in a fundamental change in the traits of the population (e.g. slower growth rate and thus smaller size). Thus, to prevent such unwanted selection knowledge of the quantitative component of relevant biological parameters should be known and monitored regularly. However, as noted above, the necessity for establishing the linkage between the trait of interest and a quantitative genetic parameter requires extensive breeding experiments, thus, may be applicable in only a few cases.

6.4 Objective #4 Exploited Species (J. Boutillier, Rapporteur)

Background

What is it? - The session on the exploited species was the first session that was an example of the ecosystem objective that dealt with productivity and processes that affect the productivity of animals that are targeted in commercial fisheries. Studying of exploited species is the objective that has had the longest history and the most sophisticated approaches with respect to examining change and trying to understand the dynamics that are driving these changes. In most instances the attributes that were measured were interpreted to explain change in relation to fishing effort.

This presentation went through the history of the data collection process for exploited species. Starting 200 years ago the first measure of change examined was the economic performance of the industry. Fisheries science then went through a variety of different phases in the 1900's from general biological studies, to catch statistics, fishery independent standardized surveys and ending with at-sea observers in the 1980's. The presentation then went through a series of general categories of indicators and the current and emerging practices associated with each general category (see Section 8.3.4):

- Population Dynamic Indicators
- Survey-based Indicators
- Biological Indicators
- Ecological and Environmental Indicators
- Fishing Industry Indicators
- Integration

Why is it important? - Studying exploited species is basically conducted to meet two objectives:

1) To prevent growth overfishing. What size of animal should be harvested to allow for maximum production (this is a model of growth rates and natural mortality rates). The modelling has changed recently to recognise that different sized animals demand different prices. That is, we don't always have to catch the most we have to catch the most valuable. The model now incorporates a third component, which is price at size information.
2) To prevent recruitment overfishing. This assumes that there is a model that relates spawning stock size to recruitment. This modelling exercise has changed over time and now incorporates other aspects to understand the process such as environmental conditions. This latter objective is hard to get a handle on and there are few fisheries in the world that base their management on a stock recruitment relationship. The exceptions are salmon fisheries and the prawn trap fishery on the west coast of Canada.

Management of fisheries to prevent growth overfishing is usually controlled through the use of size limits, gear restrictions e.g. mesh size etc. and/or time and area closures e.g. closed nursery areas. Recruitment overfishing on the other hand is not easily understood in relation to a stock recruitment relationship and so proxy measures such as results from sequential population models are used to understand how populations respond under various levels of spawning stock biomass or the exploitation rate.

How is it measured? - Each of the general categories has a variety of indicators which can be interpreted and provide a measure of the change or performance of the stock under various abiotic and biotic conditions. Not all indicators are available for most species.

- Population Dynamics Indicators: uses catch at age data (expressed in biomass), length and age composition of samples from the catch and average weight at age in the samples.
- Survey-based Indicators: uses indices of biomass, recruitment and estimates of total mortality to either fit into a Population Dynamics model or to set their own Metrics or Reference points. Spatial indicators are now being applied as independent indicators of stock condition e.g. size of area in which 75% of the biomass occupies.
- Biological Monitoring Indicators: uses size and age composition of the population from surveys, growth and condition, size and age differences in fecundity, spawner experience etc. This information is often difficult to interpret on their own but are critical when trying to understand the processes that force the system.
- Environmental/Ecological Indicators: physical and chemical indices are often used in conjunction with biological characteristics to explain variations in size at age, condition, mortality etc. Emerging indicators would include predator or prey abundance indices. The tie in with bottom typing is critical to understand when designing surveys or interpreting catch and effort statistics.
- Fishing Industry Indicators: use catch and effort statistics, which are applied to quota monitoring. Additional important information includes the amount and fate of by-catch and habitat impacts. Emerging as an interesting source of data are systematic surveys of fishers perceptions of recent trends in biomass and recruitment. Compliance with regulations such as discard limits, size limits, etc. have been proposed for use as an indicator of stock status i.e. better compliance with high stock sizes.

- Integration: this is not an indicator but a way of interpreting a compilation of indicators. It looks at a compilation of these indicators and applies pre-agreed decision rules to the report card, stoplight, radar plots or precautionary decision making frameworks.

Important cross linkages and challenges - As we go from a single species management regime to one that applies a more ecosystem approach to management we will see the rules change from those based on the health of the target species to those based on the impacts and health of the environment. We will begin to see changes in the decision rules and report cards from precautionary single species target and limit reference points to ecological indicators that measure the impacts and changes to the whole ecosystem caused by fisheries. As we enter into this paradigm shift we will see more emphasis being placed on the non-targeted species impacts, decision will be based not only on the impact on habitat of the targeted species but also cohabiting organisms. Fisheries will now be evaluated on the impact on a more holistic manner and decision will be based on impacts of diversity indices, impacts on species at risk. Management decisions will be based on methods of fishing that are selective for non-target species. There are major shifts occurring in the way we do business and there are a number of challenges that will face us as we detect, interpret and try to mitigate changes. Some of the challenges that will face us include: bringing in new sources of data such as traditional knowledge; organising, collection, storage and retrieval of data; integrating this information into the larger picture, and developing the tools to interpret this information. Most of the fishery and fished-species indices depend on long time-series of data. As environmental and productivity conditions change, it may mean that to understand the fishery time series so that we can be predictive, the time-series needs to be divided into poor and good productivity regimes.

Discussion

Based on the discussion following presentations for this ecosystem objective, key points to consider when developing an LMR-GOOS monitoring system were identified:

1. The importance of fishery independent surveys.
2. The inclusion of geo-referencing when collecting fisheries statistics is necessary if we are going to incorporate bottom-typing information into the assessment process.
3. Age composition is an important data set when trying to understand the processes that are forcing critical stages in an animal's life.
4. More emphasis needs to be put on the proper collection and interpretation of traditional knowledge.
5. Monitoring can not be done by DFO alone and its development will depend on building of strong collaborations with stakeholders.

6.5 Objective #5 Non-exploited Species (J. Boutillier, Rapporteur)

Background

What is it? - This session dealt with the use of information on ecologically dependent non-target species to provide an indication of change and the general health of the ecosystem. There are basically two ways of approaching this problem: *lumping* everything together and trying to describe how the assemblages function or by *splitting* the system into little building blocks and studying how these are functioning and behaving in relation to other building blocks. The presentation then looked at these non-targeted species and broke them into their roles within the ecosystem which included:

- Non-ecologically dependent species e.g. Monkfish
- Non-ecologically dependent species that are affected by the fishery as by-catch e.g. Barn-door Skate
- Ecologically dependent species which are looked at in two functional modes from a top-down perspective and from a bottom-up perspective.
  - Predators
  - Prey which would also consist of the special case of cannibalism.

Why is it important? - Study of Ecologically Important Non-targeted Species allows us to better understand the indirect and direct impacts of anthropogenic activities on the ecosystem as a whole. This might add in our understanding of how by-catch may lead to the extirpation or extinction of by-catch species such as the Barn-door Skate. It will also give us a better understanding of how the target species may respond to overfishing depending on it's role as a predator or a prey. It will help give a better picture of the processes that are at work and will allow us to better understand and forecast the changes. It should be noted that change is more readily detectable in species that are shorter-lived and faster growing then in species that are long-lived and slow growing.

How is it measured? - Developing indicators for non-exploited species is generally more difficult because of the absence of commercial data and biological sampling. Some information can be obtained through data gathering programs such as: fishery independent surveys, stomach sampling, scat analysis, at-sea observer by-catch sampling and monitoring the health and condition of predators and prey.

Another approach that was also discussed included the use of experimental unperturbed control areas to understand the difference between changes that occur naturally and those caused by anthroprogenic activities. Also emphasised in the presentation was the need to cover off non-sampled components of the environment through the use of complimentary surveys e.g. the combining of a pelagic survey with a bottom surveys or pup counts of predators such a seals.

There are a variety of models used to monitor and interpret change varying from tracking single species abundance to multi-species balance and dynamic models.

Important cross linkages and challenges - Programs such a at-sea observer by-catch sampling are generally not sophisticated enough to pick up changes to some of the more rare and endangered species because of the lack of systematic capability of the observers. As such there has to be a major rethinking of delivery of key data gathering programs to insure that they are to deliver meaningful data and address needs such as our obligations under SARA (Species at Risk Act). Again as we broaden the scope of management from a single species health to impacts on the ecosystem we are begining to see decisions affecting fisheries that are based on the impacts of things such as non-exploited species that are ecologically dependant. This can be seen in the CCAMLR studies which set limit reference points for krill in the Antarctic so as not to impact on the whale populations. Non-target species have not been sampled properly in fishery independent survey or in at-sea by-catch programs.

Discussion

Based on the discussion following presentations for this ecosystem objective, key points to consider when developing an LMR-GOOS monitoring system were identified:

1. Exploitation of forage species requires not only monitoring of the target species but also key predators in order to understand bottom-up effects.
2. There is generally poor collection of non-target species data in research surveys because there are insufficient resources to process data at this level and only the target-species have been adequately sampled.
3. Even in programs that are supposed to monitor such things as by-catch the emphasis is generally on other targeted species. The main reason is that we have still not fully recognised the utility of capturing information on Non-exploited species even though they are ecologically dependant. The second reason is that there are insufficient skills in systematics to do a proper job of getting correct identifications of these non-exploited species.
4. There must be clear objectives when designing the data collection process.
5. It is easier to understand implications on predator (bottom up approach) then it is to understand the implications on prey (top down approach). Need to monitor top predators is absolute as they act as high-level integrators of the processes and environment under them.
6. Egg and larval surveys are easy to get trends in bio-diversity.
7. The use of proxy indicators such as stable isotopes would allow us to identify changes in the biomass-by-tropic levels. This may prove to be useful in a nested sampling program that would combine a simple change indicator to an expensive process sampling program such as stomach sampling.

6.6 Objective #6 Emergent Properties of Ecosystems (P. Pepin, Rapporteur)

Background

Jake Rice provided a thorough summary of methods and principles that could be used to identify changes in marine ecosystems. He stated that knowledge is fundamental to understanding why indicators of ecosystem properties change. With a good narrative associated with any indicator of ecosystem state, the index itself adds nothing to our understanding. In fact, it may create a negative opportunity for clients to focus on "the number" rather than on the interpretation of the change that is taking place.

Good indicators should change when the ecosystem changes and remains stable when the system is stable. They should be monotonic if possible and ideally, they should be characterised by interval changes.

Rice outlined the pros and cons associated with a wide suite of potential tools used to interpret changes in the properties of ecosystems.

Discussion

There was considerable discussion about the views presented in Rice's paper, particularly about the conviction expressed throughout the entire range of metrics considered in his assessment.

There was consensus that communication to user groups represents the key element in outlining changes in ecosystems and determining their cause. Particular attention needs to be paid to concepts that can be communicated in the simplest of terms as this can be used to guard against the development of dogmatic thinking in both scientific advisors and client groups.

The use of size spectra, with some identification of functional groups within them, could serve as a good basis for developing descriptors of ecosystem properties. Changes in the form or distribution of observations within the size spectra can serve to identify both drastic and gradual shifts that are taking place within marine communities.

There was considerable concern over the interpretation of richness indices and their sensitivity to extirpation of species from ecosystems. The number and types of assemblages within a system may change over time but these may not be detected by some indicators.

It was not possible to reach a consensus about the nature of the indicators that should be used to measure the emergent properties of ecosystems. The use of a large number of metrics, and a careful real-world and simulated study of their behaviour over time could be used to demonstrate how they respond as change occurs.

Jake expressed a serious concern about the use of trophic indicators in the monitoring of changes in ecosystem properties. True measurement of trophic status should not be based on apparent changes in the relative biomass flows inferred from ecosystem models. For example, there must be an on-going collection of stomach information in order to make any realistic comment about changes in prey-predator relationships. Previous experience from the North Sea multispecies assessment model indicates that such collections do not have to be continuous but they have to be undertaken on time scales that are characteristic of long term changes in marine ecosystems (e.g. decadal). However, it is critical to emphasise that inferential statements must be supported by data collections in order to accurately identify changes in ecosystem properties.

Other potential indicators that were discussed but not presented in Jake's attached manuscript included the identification of changes in the spatial distribution characteristics of species or species assemblages and how these change over time. Although the issue was discussed during the session dealing with Objective #1, Ecosystem Diversity (Section 6.1), spatial representation of shift in distributions or interactions is often not identified by most metric currently used to describe ecosystem properties. Within this topic, there comes a need to identify the scales at which properties should/must be measured and how they can be interpreted but this requires more discussion than could be afforded during this session. Stable isotope composition may also be more general indicators of trophic relationships and can serve as simpler metrics of trophic interactions than stomach content analysis. However, as with many other indicators, there must be a careful consideration of the responsiveness and accuracy.

7 Issues

7.1 Infrastructure

A program as large as LMR GOOS needs to consider the administrative needs of its implementation. Two aspects of this are discussed here: program management (how the project is coordinated and managed) and data management (how the data products are processed and archived). Both are critical aspects of any large-scale program such as LMR GOOS.

Program Management

Ecosystems do not necessarily conform to administrative boundaries and thus some management process is required to transcend these boundaries to encourage development of an ecosystem view. As well, LMR GOOS is a program that links short-term process research with observation made through long-term monitoring. The latter necessitates continuity over a number of years and, by inference, scientific careers. The extent of the program necessitates that there be a long-term commitment to it. Further, due to the complexity of the research required, it is not efficient to conduct the same research in all areas but rather, it is more appropriate to employ scientific expertise available in one laboratory to problems on an ecosystem scale.

For these reasons, LMR GOOS will need strong central coordination if it is to be a success. This can be achieved though establishment of a National Coordination Office. This office would ensure that the program remains relevant and funded, and that the latter is sustained and predictable. It would serve as a focus for interaction with other levels of government and other countries, and facilitate public and political awareness. An important role of the National Coordination Office would be coordination of bottom-up research priorities with top-down strategic priorities defined by national agencies. This would greatly improve the chances for strategic funding.

Data Management

The integration of data management is of central importance to the success of the LMR GOOS program. It needs to allow the constructive and timely interaction among monitoring, research and management (perhaps using new web technologies as experimented with at BIO), to be flexible enough to accommodate disparate data types and scales of sampling, and to establish protocols and procedures for quality assurance, access, usage, timely dissemination, and archiving of data. The latter is particularly important given the need to safeguard the legacy of the data for future generation of scientists and resource users.

For individual scientists working on specific projects, data management is not generally an issue. However, in programs such as LMR GOOS, which depend upon data being collected, processed and archived on central servers by a number of scientists working at different geographical locations, data integration can be a formidable task. Data integration problems have been encountered in other large-scale programs (i.e. ECNASAP initiative) and were highlighted as part of the DFO Science Strategic Plan. As a consequence, a DFO data management policy has been developed and will be in place for 2000 – 2001. This policy should be used to direct data management in LMR GOOS.

7.2 Next Step?

Canadian representatives from both DFO and universities continue to participate in the development of the international strategic design and implementation plans for the two GOOS panels, the Coastal Ocean Observations Panel (COOP) and the Ocean Observations Panel for Climate (OOPC); living marine resources falls principally within COOP. The ecosystem objectives framework (Sinclair et al. 1999) proposed for LMR will be put forward for the broader COOP monitoring system.

Nationally, dialog among government and NGO scientists, managers and stakeholders continue in an effort to better define ocean management areas (OMAs) and ecosystem objectives and to develop relevant, interpretable and practical indicators. Ultimately, the end-users will determine the ecosystem objectives for integrated oceans management. In parallel, efforts are underway to develop a national monitoring strategy that will identify core observations and insure some consistency in data collection and products across regions while still addressing region- specific requirements.

Some discussion at the workshop wrap-up revolved around how this will be accomplished. Among the suggestions posed was a proposal for a series of regional workshops to "operationalise" the process by, for example, developing regional "pilot" projects, an approach similar to that adopted by international LMR-GOOS (IOC, 2000). Concern was expressed, however, that small pilots may not carry with them a commitment for long-term funding once the pilots are completed; sustained funding is fundamental for the implementation of a long-term monitoring program. A suggested alternative is to define a large program now, secure the funding and then consider pilots to fine-tune or "regionalise" the monitoring network. To develop the national program, working groups for each of the ecosystem objectives would be struck to define and establish needs. These WGs would put together proposals addressing the identified needs that would then be passed on to a National Coordination Office (see Section 7.2 above) tasked to review the proposals and use that information to define common infrastructure elements. This would then be sent back to the WGs for final consideration. The approach that will ultimately be used to carry this forward is still in the planning phase.

References

IOC. 2000. LMR-GOOS Strategic Design, Draft Report, July, 2000.

Sinclair, M., R. O'Boyle, L. Burke, and S. D'Entrement. 1999. Incorporating ecosystem objectives within fisheries management plans in the Maritimes region of Atlantic Canada. ICES CM 1999/Z:03.

8 Recommendations

Following LMR-GOOS workshop, two additional DFO workshops were held to further clarify and define the ecosystems objectives framework for addressing issues at the regional (Workshop on the Ecosystem Considerations for The Eastern Scotian Shelf Integrated Management – ESSIM- Area, BIO, 19-23 June, 2000) and national level (National Workshop on Objectives and Indicators for Ecosystem-based Management, Sidney, BC, 27 Feb-2 Mar, 2001). In addition, an international workshop was convened to begin the process of merging the GOOS non-climate modules, LMR, C-GOOS and HOTO, into a single panel, the Coastal Ocean Observations Panel COOP (Coastal Ocean Observations Panel, Session I, San Jose, Costa Rica, 15-17 Nov, 2000). The recommendations outlined below, therefore, reflect points raised during the LMR-GOOS workshop and as well some points raised during subsequent workshops as they relate to Canada's role in GOOS. The recommendations have been grouped into three categories; strategic, administrative and research.

Strategic Recommendations

1. The ICES/SCOR Symposium on the Ecosystem Effects of Fishing, held in Montpellier in March 1999, provided an operational framework for the incorporation of ecosystem considerations within fisheries management. The framework was subsequently accepted by DFO Policy Committee (June 2000) as part of the approach to the incorporation of ecosystem objectives within fisheries and oceans management. It is recommended that this framework be adopted as a starting point for the development of a "living marine resources" observing program for Canada, and presented to COOP-GOOS for their consideration as an international template.

2. ICES/IOC has formed a Steering Group for the coordination and implementation of GOOS activities in the North Atlantic. It is recommended that Canada use this mechanism for the development of COOP components of GOOS with United States (and possibly with France and Denmark for St. Pierre and Miquelon and Greenland issues).

3. PICES has formed a working group to address monitoring needs for the North Pacific. It is recommended that Canada use this mechanism for the development of COOP components of GOOS with relevant nations in the North Pacific.

4. There are numerous international planning activities directed at climate and ecosystem monitoring in the arctic, under the auspices of the Arctic Council (including programs such as the Arctic Monitoring and Assessment Programme [AMAP] and Conservation of Arctic Flora and Fauna [CAFF)]), and the International Arctic Science Committee (IASC) and the Arctic Ocean Sciences Board (AOSB) among others. Nationally, DFO has included Arctic Ocean monitoring in its submissions to the Climate Change Action Fund. It is recommended that Canada use these mechanisms for the development of COOP components of GOOS with relevant nations in the arctic.

5. The ecosystem trawl surveys conducted by DFO and NMFS along the eastern seaboard from Cape Hatteras to Cape Chidley provides an exceptional data set to monitor large scale long term changes in fish and invertebrate demersal communities. It is recommended that DFO contact NMFS about merging the data sets from the relevant trawl surveys and propose this biological observational program as an Initial Observing System for the COOP component of GOOS.

6. Canadian participation in LMR, HOTO and Coastal panels has been active, including DFO and University members. At present Keith Thompson and John Cullen from Dalhousie University are expert members of COOP-GOOS and Savi Narayanan has been the national

representatives. It is recommended that DFO continue to participate actively in the COOP GOOS Panel.

Administrative Recommendations

7. The "living marine resource" monitoring programs in the Pacific, Arctic and Atlantic are at different stages of development. It is recommended that a DFO national COOP Working Group (C-COOP WG) be established to coordinate the development and implementation of the Canadian COOP program. The C-COOP WG would report to NSDC.

Research Recommendations

8. The proposed ecosystem objectives and indicators for integrated oceans management need to be more clearly defined so that there is a common understanding by both specialists and stakeholders. It is recommended that the ecosystem objectives and indicators, as elaborated upon at the DFO Dunsmuir Workshop (February 2001), be described in an operational and easily understood manner.

9. Some gaps in the present monitoring activities relative to the generation of data products for the indicators of ecosystem objectives were identified during the workshop. It is recommended that an evaluation of the state of the ecosystem for the northwest Atlantic be carried out initially using the AZMP observations, and other relevant data from fisheries monitoring activities. This should be expanded to include observational data from other regions (Pacific, Arctic) subsequently. The "state of the ecosystem" would be described in relation to the proposed ecosystem objectives for integrated oceans management.

10. For proposed objective 1, the maintenance of "diversity of ecosystem types" there is a need for the spatial classification of the benthos, palegic and fish communities within Canada's EEZ. There is also a need for the definition of the geographical proportions of the diverse ecosystem types that need to be protected from disturbance by categories of ocean industry activities. This later need is particularly acute for benthic communities. It is recommended that research be carried out in support of spatial classification of "ecosystem types" and the use of zoning of ocean uses for their protection.

11. For proposed objective 2, the maintenance of species diversity, there is a need for improved definition of evolutionary significant units (ESUs) for marine "species of special concern". It is recommended that research on ESUs for such species be supported, as a prerequisite for establishment of spatial scales for monitoring.

12. For proposed objective 3, the maintenance of genetic diversity within species, it was evident that monitoring of this level of marine biodiversity is in the exploratory phase and could be very costly. It is recommended that, as a start, the spatial distribution of spawning aggregations of "species of special concern", as well as for commercially exploited species, be part of relevant monitoring programs.

13. For proposed objective 4, the maintenance of commercially exploited species, it was recognized that the fishing industry, First Nations as well as DFO conduct relevant monitoring activities. It is recommended that multiple indicators be explored (in addition to

traditional indicators of stock biomass, recruitment and fishing mortality), and that the traffic-light approach be further developed for analysis of the indicators.

14. For proposed objective 5, maintenance of dependent species, the approach being taken by **CCAMLR** was considered to be useful. It is recommended that the fisheries monitoring programs collecting by-catch information be routinely analyzed, and data products be reported on.

15. For proposed objective 6, maintenance of emergent properties of marine ecosystems, it was recognized that gaps in understanding of ecosystem structure and function make it difficult to arrive at consensus on useful indicators. It is recommended that a range of indicators of properties of marine ecosystems be reported on in an exploratory manner.

16. For the interpretation of the causes of observed changes in indicators for the proposed ecosystem objectives (in relation to natural variability and diverse impacts of ocean industries), it was recognized that the "living marine resource" monitoring system needs to include observations beyond those that generate the data products for the indicators. It is recommended that the Canadian COOP-GOOS monitoring program include measures of oceanographic properties (physical and biological) necessary for the assessment of causality.

17. It was recognized that there is a shortfall in resources for the routine analysis of data presently being generated by diverse monitoring activities of relevance to COOP-GOOS. It is recommended that the NSDC consider steps to be taken to strengthen capacity for analyses of monitoring programs, including the role of modelling tools.

9 Appendices

9.1 Workshop Agenda

Canadian LMR-GOOS Workshop
29-30 March 2000
Bedford Institute of Oceanography
(Main Auditorium)

29 March

0900 – Welcome/Logistics (G. Harrison)
0915 – International LMR-GOOS/Ecosystem Objectives (M. Sinclair)
1000 – BREAK
1030 – Canadian LMR (G. Harrison)
1045 – Overview of AZMP (P. Pepin)
1100 – Obj#1 Ecosystem diversity (D. Gordon) Respondent: Gary Sprules
1130 – Discussion
1230 – LUNCH
1330 – Obj#2 Species diversity (R. Bradford*) Respondent: J. Musick**
1400 – Discussion
1500 – BREAK
1530 – Obj#3 Genetic variability within species (E. Kenchington*) Respondent: R. Doyle
1600 – Discussion

30 March

0900 – Obj#4 Exploited species (P. Fanning) Respondent: J.-C. Brêthes
0930 – Discussion
1030 – BREAK
1100 – Obj#5 Non-exploited species (B. Mohn) Respondent: D. Agnew
1130 – Discussion
1230 – LUNCH
1330 – Obj#6 Emergent ecosystem properties (J. Rice) Respondent: V. Christensen
1400 – Discussion
1500 – BREAK
1530 – General Discussion
1700 – Wrap-Up/Closing Remarks (M. Sinclair / G. Harrison)

31 March

0900 – 1700 – LMR Committee – Draft Report

*Talk presented by Respondent
**Ed Trippel lead discussion in this session

9.2 List of Participants

Name	**Affiliation**
David Agnew	Imperial College
Jim Boutillier*	DFO-Nanaimo
J.-C. Brêthes	UQAR
Alida Bundy	DFO-BIO
Matin Castonguay	DFO-IML
Villy Christensen	UBC
Brad deYoung	Memorial University
Roger Doyle	Genetic Computation Ltd.
Richard Eisner	DFO-BIO
Paul Fanning	DFO-BIO
Caihong Fu	DFO-BIO
Don Gordon	DFO-BIO
Doug Gregory	DFO-BIO
Glen Harrison*	DFO-BIO
Anthony Isenor	DFO-BIO
Ellen Kenchington	DFO-BIO
Peter Koeller	DFO-BIO
Serge Labonte	DFO-Ottawa
John Loch	DFO-BIO
Arran McPherson	Dalhousie University
Bob Mohn	DFO-BIO
Jack Musick	VIMS
Savi Narayanan*	DFO-MEDS
Pierre Pepin*	DFO-NWAFC
Ian Perry	DFO-Nanaimo
Ted Potter	DFO-BIO (OACO)
Trevor Platt	DFO-BIO
Jim Reist*	DFO-C&A
Jake Rice	DFO-CSAS
Bob Rutherford	DFO-BIO (OACO)
Mike Sinclair	DFO-BIO
Gary Sprules	University of Toronto
Stephen Smith	DFO-BIO
Doug Swain	DFO-GFC
Chris Taggart	Dalhousie University
Ed Trippel	DFO-SABS
Kees Zwanenburg	DFO-BIO

*Canadian LMR-GOOS Committee member

9.3 Presentation outlines, Abstracts, Working papers and Respondent comments

9.3.1 Objective #1: Ecosystem Diversity

9.3.1.1 Presentation - outline (Don Gordon)

Introduction

Focus on benthic ecosystems.
    Not as well known
    More stable with time
    Easier to describe spatially
    More likely to be affected by human activities
        Physical disturbance
        Contaminants

Keep general and generic, but illustrate with specific examples.
Covers both inshore and offshore (continental shelf)
Ideas for debate and discussion.

Definition of ecosystem diversity
    Maintain different kinds of ecosystems (spatial)
        Mud, sand, gravel, boulder, etc.
    Maintain diversity within a given kind of ecosystem (temporal)
        Species, functional groups, age and size structure.

Objectives of ecosystem diversity
    Should be set by society. Need much discussion. Iterative process over years as we learn as we go.
    Assume include maintenance of biodiversity, habitat productivity and stability (avoid regime shifts)
    Assume include multiuses such as resource extraction (renewable and non-renewable), recreation, dumping, conservation, etc.
    Assume society willing to accept some change in ecosystem properties (within limits) in exchange for goods and services provided. Not all areas necessarily kept in pristine condition.
    Assume include protecting a percentage of each habitat type from disturbance (i.e. MPAs).
    What is the best spatial distribution of protected areas (one large areas or many small ones?)

Natural variation in benthic habitat and communities must be understood. Thought to be substantial but little data. Effects of storms, ice, temperature, changes in sedimentation, etc.

What are the human activities that can affect ecosystem diversity?

- Fishing
    - Removal of biomass of targeted species and by-catch
    - Changes in predation pressure
    - Physical impacts of gear on habitat (both mobile and fixed)
    - Direct and indirect effects on benthic communities
- Oil and gas
    - Structures (platforms, pipelines, etc.)
    - Drilling discharges
    - Produced water
    - Spills
- Submarine cables
- Dumping of dredge spoils
    - Smothering and contaminants
- Causeways
- Mining
    - Excavation of aggregate

What do we need to measure (performance measures)?

1. Classification and mapping of benthic habitat and communities

Spatial analysis. Landscape ecology. (Various spatial scales (need down to about 100 m for this purpose). Not really monitoring per se since no temporal coverage (at initial stages) but needed to design monitoring programs. Need for entire Canadian seabed.

Review progress to date

Tools available:
Multibeam
Sidescan
Seismic
QTC, Roxanne
Video
Photography
Direct sampling

Examples of large spatial scale, limited resolution products:
Mapping of sediment types (King et al.)
Mapping of biophysical features (Davis et al.)

Examples of small spatial scale, high resolution studies:
Coastal Newfoundland cod habitat (Anderson)
Lobster Bay lobster habitat (Lawton)
Browns Bank (NRCan)
Gully (DFO, NRCan)
Gear impact experiments (DFO, NRCan)

SEAMAP concept (see concept paper)
  Expand and standardize existing efforts
  Federal Government lead, partnering with industry, universities and others
  Get new resources, long term

Related initiatives
  MIDI
  Sloan Foundation project

Ideal steps to mapping in future, each building on the previous:
  Multibeam for bathymetry and substrate type
  Other acoustic tools (seismic, sidescan, QTC, Roxann) for substrate type (major determinant of benthos)
  Video and photo for ground truthing substrate type and identifying visible organisms (epibenthic).
  Videograb for ground truthing substrate type and collecting infauna.

Establish classification schemes for habitat and communities
  Substrate
  Biological communities

This information once available will help us refine our objectives for ecosystem diversity. Feedback. We also need other information to feed back into defining our objectives for ecosystem diversity. This will come out of long term research programs, not monitoring. Canadian and international. Some knowledge available now but much more needed. Should be incorporated when available. This includes:

Understanding the role that different habitats play in supporting marine resources
  Spawning, nursery, feeding grounds, etc.
  Behavioural studies, how fish use habitat
  What is essential fish habitat, critical habitat

Understanding the sensitivity of different habitats to human disturbance
  Fishing gear
  Oil and gas
  Other
  What are the most and least sensitive habitats
    Some areas off limits (corals)
  Priorities for protection (input from society)

2. Temporal monitoring in protected areas

Need to understand natural variation
Long term monitoring at representative stations in different habitats in protected areas
DFO experimental sites
  Grand Banks (sand)
  Western Bank (gravel)
  Banquereau

Industry EEM programs
- PanCanadian
- Hibernia
- SOEI
- Terra Nova

3. Measure spatial extent of human disturbance

Georeferenced databases
- Fishing effort
- Oil and gas
- Cables
- Dumpsites
- Mining sites

In most cases, data being collected now. Where not, start getting data. Need to standardize, construct central databases.

4. Temporal monitoring in disturbed areas

To monitor extent of human impacts
Oil and gas EEM programs
Require industry funded EEM programs for other human activities?

Summary

Objectives

Need to start with general objectives even though not all needed data are available. Will be iterative process. Ideally need a seabed use map (zoning)

Use some areas but protect others. Variable according to ecosystem sensitivity.

Performance Measures (in priority considering practicality):
1) Mapping human disturbance of seabed for different uses
   Continuous, annually, retrospective too
2) Mapping benthic habitat and communities
   On going effort
3) Temporal monitoring at protected sites to track natural variation
4) Temporal monitoring at disturbed sites to determine impacts of human activities

Products
- Annual maps of the spatial extent of disturbance
- Benthic habitat maps (substrate and communities)
- Reports of temporal changes in ecosystem diversity

Reference Points
- Percent of each habitat actually disturbed each year

Use the results to make management decisions
- Develop knowledge and models to predict the impact of proposed activities
- Closures (MPAs)
  - How much to protect for each habitat type
  - Spatial pattern
- Yes or no decisions on proposed activities
- Mitigation measures
- Compensation
- EEM programs

9.3.2 Objective #2: Species Diversity

9.3.2.1 Presentation - outline (Rod Bradford)

In accordance with the *Canada Oceans Act*, the Department of Fisheries and Oceans is developing a strategy for the "management of marine ecosystems". Maintenance of biodiversity will be one important element of the strategy. In order to meet this ecosystem objective procedures to monitor species diversity and the status of individual species will be required.

The purpose of this presentation is to provide an overview of the issues associated with monitoring species diversity in marine ecosystems. The presentation will include:

1.) a brief overview of how the status of marine species in Canada is to be assessed within the context of extinction risk.
2.) a brief overview of performance measures as currently adopted by the Committee on the Status of Endangered Wildlife in Canada, and
3.) a review of extinction events in the marine realm and what these can tell us about how to monitor biodiveristy in marine ecosystems.

The following background material is attached.

1) Process, Categories and Guidelines for Designating Species at Risk in Canada
2) (Committee on the Status of Endangered Wildlife in Canada, Oct. 3, 1999, Hull, Québec)
3) IUCN categories and criteria for extinction risk
4) Powles et al. in press. Assessing and Protecting Endangered Marine Species. ICES-SCOR Symposium on Ecosystem Effects of Fishing
5) List of species at risk in the Maritimes

Further recommended reading:

Musick, J.A. 1999. Criteria to define extinction risk in marine fishes. Fisheries-Bethesda. 24(12): 6-12.

Powles, H, M.J. Bradford, R.G. Bradford, W.G. Doubleday, S. Innes and C.D. Levings. 19xx. Assessing and protecting endangered marine species. ICES-SCOR Symposium on Ecosystem Effects of Fishing, MS#C3, Montpellier.

9.3.2.2 Process, Categories and Guidelines for Designating Species at Risk in Canada (Committee on the Status of Endangered Wildlife in Canada, Oct. 3, 1999, Hull, Québec)

Assessment Process:

1) Eligibility.
   a) *Taxonomic Level*: species > subspecies > population of national significance.
   b) *Native Species*: in Canada for >50 years
   c) *Regularity of Occurrence*: excluding vagrants

   d) *Non-Resident or Migratory Species*: requires habitat in Canada for a key life history stage.
   e) *Special Cases*: high risk of extinction in primary range outside Canada

2) Assessment using COSEWIC guidelines:
   a) Quantitative
   - IUCN Red List Criteria
   - of the 118 species of marine fishes considered by the IUCN's Species Survival Commission (1996) to be at risk of extinction, 70% were designated based on the IUCN A (decline) criterion
   - the decline criterion may not be suitable for some marine species.

   b) Contextual
   - repopulation possible by a conspecific population?
   - existence of local adaptations
   - lack of suitable habitat
   - status of extra-regional populations
   - reliance on immigration by extra-regional populations

   c) Other
   - need assessment tools that can accomodate life-history variability.
   - COSEWIC will consider any significant species -specific life-history characteristics that are not adequately assayed by the quantitative assessment (for example: fecundity, Allee effect, specific life-history strategies, age at maturity).

3) Assign COSEWIC category.
4) Record rationale and supporting information.
5) Forward SAR List, rationale and supporting information to CESCC.
6) Joint release of Species at Risk List by COSEWIC and CESCC.

Assessment Categories:

- *Extinct* - A species that no longer exists.
- *Extirpated* - A species no longer existing in the wild in Canada, but occurring elsewhere.
- *Endangered* - A species facing imminent extirpation or extinction.
- *Threatened* - A species likely to become endangered if limiting factors are not reversed.
- *Special Concern* - A species that may become Threatened or Endangered because of a combination of biological characteristics and identified threats.
- *Data Deficient* - A species for which there is inadequate information to make a direct, or indirect, assessment of its risk of extinction.
- *Not at Risk* - A species that has been evaluated and found not to be at risk.

9.3.2.3 List of Species at Risk in the Maritimes

Species	Status
Leatherback Turtle	Endangered
Atlantic right whale	Endangered
Atlantic whitefish	Endangered
Atlantic salmon - inner Bay of Fundy	Endangered (proposed)
Harbour porpoise	Threatened
Lake Utopia dwarf smelt	Threatened
Atlantic sturgeon	Threatened
Northern bottlenose whale	Vulnerable
Sowerby's beaked whale	Vulnerable
Humpback whale	Vulnerable
Fin whale	Vulnerable
Shortnose sturgeon	Vulnerable
Atlantic cod	Vulnerable
Redbreast sunfish	Vulnerable

9.3.2.4 Respondent comments – outline (Jack Musick)

Threats to marine fishes

1. Rarity
2. Small range and endemics
3. Specialized habitat requirements- anadromous species: sturgeons, salmonids, eulachon
   estuarine nurseries- hard bottom habitats
   Paragonia, etc.
4. Life History limitation: greatest threat to marine fishes in general:
   K-selected species at risk
   long-lived
   late maturity
   low fecundity or naturally infrequent recruitment (iteroparity), bet hedging
   mixed species fisheries- by-catch and vulnerability of late-maturing species; density dependent compensation may be minimal

Risk Criteria

1. IUCN- Publication
2. A. F. S. Alternatives- based on "r" intrinsic rate of increase or surrogate life history parameters

Management or Conservation Units

1. District Population Segments (D. P. S.) or Evolutionary Significant Units (E. S. U.):
   A population that is

a.) Substantially reproductively isolated from other conspecific units b.) Represents an important component in the evolutionary legacy of the species

2. Within species, different populations may have different vital rates and thus different vulnerability ex: northern cod, barndoor skate
3. Canadian populations in colder habitats are more vulnerable because of slower growth and later maturity
4. Communities: dynamic- multiple equilibrium points
   because of different demographics, geographically distinct but taxonomically similar communities may function differently

Hot spots: areas where several D.P.S.s may be at risk

F. S. initial analysis

1.) Florida Keys- endemic and habitat problems
2.) Gulf of California- overfishing K-selected groups
3.) Puget Sound and adjacent Canadian waters: overfishing K-selected rock fishes and ecosystem shift with major range extensions of California Sea Lion

Management Options

1.) Recognition of vulnerability of late maturing species i.e. particularly populations at higher latitudes or colder habitats.., precautionary management. Need to monitor K-selected species in mixed species fisheries
2.) Need for large marine protected areas MPA.s

M.P.A.s

1.) may provide insurance against the imprecision of traditional fisheries management tools (uncertainty of estimates of fishing targets or thresholds i.e. M.S.Y.)
2.) Protect physical habitats
3.) Protect age structure of stocks
4.) Protect community structure within the ecosystem

Size of MPAs depend on management objectives- may be a few km^2 to 1000s km^2
marine national parks or forests

Regulation Options in M. P. A. s

1.) No take- no harvest at all
2.) Limited harvest with non-destructive gear (i.e. hook and line)
3.) Rotating protected areas with managed take- protection of spawning aggregations and areas

M.P.A. systems: If MPAs are to be effective for fisheries management they must be strategically located and of sufficient size to consider the ecology and community structure of those species to be protected as well as the dynamics of the entire ecosystem-
i.e. egg and larval drift, seasonal migration, etc.

Community Analysis and Monitoring:

Management should seek to be proactive to protect species before they need to be listed as threatened or endangered and to monitor community structure and ecosystem function

1.) Define fish communities based on ordination and classification of existing fishery independent survey data- seasonally
2.) Identify dominant species important to fisheries
3.) Identify vulnerable (K-selected) species
4.) Choose target communities for monitoring and modeling

Essential Fish Habitat Analysis (use all available data sources)

1.) Define E. F. H. for important fisheries species
    a.) identify E. F. H. by relative use (ecological importance) by target species
    b.) determine availability of habitat (how much is there)
    c.) determine vulnerability of habitat (is it threatened by anthropogenic activity)
2.) Determine congruence among E. F. H.s for multiple fisheries species of concern
    a.) prioritize and monitor most important of E. F. H.s

9.3.3 Objective #3: Genetic Variability Within Species

9.3.3.1 Working paper (Ellen Kenchington)

Introduction

The purpose of this working paper is to provide reference for discussion on possible performance measures, reference points and management tools towards the protection of biological diversity of marine organisms at the gene level. Modifications to this working paper may be made prior to the meeting. This working paper is not to be cited without permission of the authors and is only provided as background information for the presentation.

Biological diversity at the gene level

A gene is a hereditary unit that helps to determine a trait. The DNA sequence of a specific gene may not always be exactly the same. There may be some differences in the sequence, resulting in different variants of the same gene. Such alternate variants of a specific gene are called alleles. The number of different alleles is a measure of genetic variation. The different alleles of a specific gene often occur in different frequencies in different populations (allele- or gene frequencies). The genetic variation of a species is therefore distributed both within populations, expressed as different allele combinations between individuals (so called genotypes) and between populations (in the form of differences in occurrence and frequency of alleles between populations).

A population acquires new alleles primarily through the immigration of individuals from surrounding populations (gene flow or genetically effective migration), and through the process of random change of the DNA sequence (mutation). Apart from these two processes the number of alleles in a population is determined by the size of the population and the selective forces that particular alleles may be subjected to. In general mutations occur very seldom, however, there are cases where high levels of pollution or radiation have been shown to alter mutation rate. From an evolutionary perspective (tens of thousands of years), the process of mutation is the only way in which genetic variability is created, and without mutations there would be no biological diversity.

Different populations diverge genetically through the processes of natural selection and genetic drift Natural selection can maintain or deplete genetic variation depending on how it acts. When selection acts to weed out deleterious alleles, or causes an allele to sweep to fixation, it depletes genetic variation. When heterozygotes are more fit than either of the homozygotes, selection causes genetic variation to be maintained. Through the process of natural selection individuals which carry particular alleles in specific environments are favoured; they have enhanced survival and/or reproduction, and their alleles are spread to a larger extent than those of individuals who do not carry such selectively favoured alleles. The ability of a species to adapt to changes in its environment depends on the array of genetic variability present.

Natural selection acts within populations, while the genetic potential of the species to adapt to environmental changes depends on the total genetic diversity represented among populations. However, in most marine species, where the parents produce large numbers of offspring, there is large scope for local selection. Salmonids represent a group with high levels of among-population variance resulting from their homing behaviour at spawning time (e.g., Gharrett and Smoker 1993). In such species, extinction, extirpation, hybridization and loss of genetic variation within populations represent the major categories of threat to genetic diversity within species (cf., Ryman et al., 1995). However, even in species that have free-drifting larvae, gametes or spores and are ultimately distributed over a wide area, local populations can often be discerned (e.g., cod: Ruzzante et al. 1997; squid: Shaw et al. 1999). The diversity contained among-populations may be important in the long-term ability of the species to adapt to environmental change.

The Special Case of Small Populations

In all populations of a restricted size the frequency of particular alleles change randomly from one generation to the next. This process, called genetic drift, may also result in loss of genetic variation. By pure chance some of the alleles that exist in the parent generation may not be passed on to their offspring. The smaller the population, the more dramatic the fluctuation of allele frequencies, and the faster the loss of genetic variation.

Another consequence of small population size is inbreeding, i.e., the production of offspring from matings between close relatives. If a population is small and isolated, inbreeding is inevitable. In many species inbreeding is coupled with reduced viability and reproduction, reduced mean values of meristic traits, as well as increased occurrences of diseases and defects, so called inbreeding depression. The Right whale is an example of a species in the study area that has a small population size (less than 200 individuals surviving).

The rate of genetic drift and inbreeding is not determined by the actual, census, population size but by a parameter denoted effective population size or Ne. Effective population size is nearly always less than N (census size) because generally not all individuals in a population are reproductive at spawning time. Ne depends on such factors as sex ratio, variance in family size (i.e., variability in numbers of offspring per individual), temporal fluctuations in numbers of breeding individuals, overlapping generations, etc. If the sex ratio of breeders departs from 1:1, N_e and genetic variation will be reduced. An effective population of 50 males and 50 females is nearly 2.8 times larger, genetically, than one of 10 males and 90 females. If the sex ratio of breeders departs from 1:1, N_e and genetic variation will be reduced. An effective population of 50 males and 50 females is nearly 2.8 times larger, genetically, than one of 10 males and 90 females. Minimum effective population sizes of 50 to 5000 per generation have been suggested by various workers as being necessary to avoid significant losses of genetic variability over various periods of time (Franklin 1980, Lande 1995, Lynch & Lande 1998).

The effect of fishing on genetic diversity

The present rate of environmental change in marine ecosystems increases the need for genetic variability in natural animal and plant populations to respond to these changes. At the same time, human activities may be reducing the genetic variability of these populations. Loss of alleles and allelic combinations can occur extremely rapidly, i.e., within a single generation. The different rates at which genetic variation can be generated and lost is a basic concern for conservation of genetic variability within species.

Fishing mortality is a highly selective process, both with respect to the size of the organism captured and location (ICES CM1997/F:4). The fishery may also directly or indirectly favour capture of one sex over another, altering the sex ratio and/or sex-specific size frequency of the breeding population (e.g., in the study area fisheries for American lobster, shrimp target the males and females respectively). In addition, migratory stocks may be under different selection pressures in different parts of their range due to different fishing methods. Fishing therefore has the potential to effect the genetic diversity and genetic structure of a species.

Phenotypic changes associated with fisheries are well documented for a number of species and include changes in life history traits such as weight- and length-at-age, and age- and length-at-maturity, as well as morphological traits such as size and spawning period, some of which are correlated (e.g., ICES CM 1997/F:4, Rijnsdorp 1993, Rowell 1993, Millner and Whiting 1996, Trippel et al. 1997). The magnitude and direction of phenotypic change within a single generation is referred to as a selection differential. In general, modelling studies have shown that size selection favours slow-growing and late-maturing fish, although there are exceptions to this (ICES CM 1997/F:4). Such changes may arise through relaxation of intra-specific competition, response to shifts in environmental conditions (phenotypic plasticity) and to change in genetic composition; it is often difficult to establish which of these effects is responsible for the observed response.

However, for genetic diversity to be affected by fishing, there must be a genetic difference between the fishes caught and those left behind in the population (i.e., a link between phenotype and genotype). Selective breeding programs for cultured fish (e.g., salmon) and invertebrates (e.g., oysters) have shown that significant amounts of genetic heritability (the proportion of phenotypic variation that is inherited from one generation to the next) for yield-related traits (e.g., growth rate) exist. Life-history traits, being closely linked to fitness, have relatively lower heritabilities, however even these are capable of showing a substantial selection response in only a few generations (ICES CM 1997/F:4). While direct extrapolation of heritability estimates determined from breeding programs to those in wild fish stocks should not be made, this research has demonstrated clearly that there is genetic variation in those traits selected for by fishing.

The persistence of fishing-induced genetic changes will depend upon the other selective forces operating on the species, the proportion of genetic diversity affected and the reproductive biology of the species. In some cases, genetic change may not be readily reversed by altering fishing practices (Law and Grey 1989). Consequently, fishing can cause evolution of phenotypic traits of the exploited species (Law and Rowell 1993), although the time-scale over which it operates is unknown.

Identifying vulnerable lifehistory stages of threatened species

For most marine species, including those of commercial value, we have little or no knowledge of genetic variability. However, for many we have a knowledge of their life history and data on important population parameters such as growth, survivorship and age-at-maturity. This information can be used to identify vulnerable stages of an organism's life history that would have the greatest impact on its fitness. An overview of elasticity and sensitivity analyses is provided by Tim Benton and Alastair Grant in the December issue of Trends in Ecology and Evolution [TREE14(12):467-471]. There is more or less direct mathematical consequence between "selection differential" as used by Law and the concepts of "elasticity" as developed by

Caswell and others. Briefly, elasticity analysis estimates the effect of a proportional change in the vital rates on population growth rate, and sensitivity analysis estimates the impact of an absolute change. Recently, stochastic population growth rates and density dependence have been incorporated into the calculations to provide robust estimates. Benton and Grant give many examples of the application of these analyses to conservation. They illustrate how protecting adult killer whales has a greater impact on the population growth rate than the same proportional changes in other vital rates. According to their model, a 1% change in the probability of survivorship once adulthood has been obtained can increase the population growth rate by 54%. Conversely, a 1% change in the fecundity of adults only increases this parameter by 5%. Benton and Grant see these as an advancement over population viability analyses (PVA) which have proven to be too imprecise over short time scales. This approach could be very useful in identifying critical stages for protection toward the preservation of large population sizes and concurrently genetic diversity.

General guidelines for conservation of genetic diversity

Two of the most fundamental general conservation genetic recommendations are to maintain as much as possible of natural ecosystems and to assess the genetic population structure. By maintaining intact ecosystems large populations may be conserved in a natural setting to which adaptation may have occurred, and in which the evolutionary forces may continue to act.

To enable adequate management and conservation of marine organisms it is vital to gather information on the population genetic structure (e.g., Ryman 1981; Allendorf et al. 1987). This information is essential for illuminating basic issues such as "what are we managing?" and "what do we want to conserve?".

Management measures for conservation of genetic diversity

Management strategies that maintain large spawning stock biomass, prevent overfishing on spawning grounds, conserve sex ratios toward equal numbers of males and females and prevent extreme fluctuations in population size are likely to have some positive effect on genetic diversity (ICES CM 1999/F:1).

Elasticity and sensitivity analyses could be employed to determine the life history stage that would contribute most to population growth of target species if enhanced and specific management measures could be implemented to meet the recommendations. These same models could be used to estimate the response of the population to change in vital parameters and the paramaters themselves could become criteria for protection with quantified performance measures associated with them. Through simulation threshold levels for population performance may also be determined.

Census and effective population size per generation (Ne) must also be considered. Levels of Ne (e.g., <50, <500, < 1000, < 5000, 5000+) could be used to classify target species for risk of genetic loss ranging from extinction to no risk). Similarly census data on total population size per generation (N) could be used when Ne is unknown. In this case larger numbers would be required as performance measures (i.e., <1000, <5000 etc.). Other population factors to consider include changes in the number of progeny per parent and catastrophic declines in population number. For brown trout these have been ranked using the following criteria:

Precipitous decline	(number of spawners<500; progeny:parent<1)
Chronic decline or depression	Declining? 10% per year over the last 2-4
Recent catastrophe	>90% reduction in population size within one generation 50-90% reduction in population size within one generation 10-50% reduction in population size within one generation

Recommended reading

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9.3.3.2 Performance Measures for the Protection of Genetic Diversity within Species

Performance Measures	
Applicable to All Marine Species	**Comment**
Effective population size (N_e)	Established reference targets are especially relevant to salmonid fish populations, locally adapted species (i.e., naturally rare, patchily distributed and with low dispersal ability) and to predatory species of intrinsic rareness, generally with low reproductive rates (e.g., large sharks, marlins, some tunas, harbour porpoises, whales). These targets are too small for classic marine organisms (large population sizes, high fecundity, pelagic larvae and wide distributions) which can be threatened with effective population sizes several orders of magnitude greater than established targets. The measure is still appropriate for these species but the targets must be re-evaluated. N_e can be indirectly estimated using genetic techniques.
Total census population size (N_c)	This measure is used as an indirect measure of N_e and it is commonly assumed that N_e is 1/5 of N_c. The relationship between the two variables is not a constant multiple when census size fluctuates, and selective fishing and spawning variability can influence it.
Population fluctuation	Many species have naturally fluctuating populations. Each time a species goes through a period of extremely low numbers there is an associated loss of genetic diversity (called "bottlenecking"). For these species it is important to monitor deviations of the population minima from the long-term average in order to detect the possibility of extinction.
Population fragmentation	Fragmentation of populations can alter gene flow with subsequent changes to genetic diversity.
Range contraction	A reduction in range can arise through loss of local populations or through changes in the behaviour of migratory species. Many species of marine organisms have localized spawning grounds with separate spawning components. Reduction in the number of spawning populations may indicate the loss of one or more stock components and associated genetic diversity.
Sex ratio	Significant deviations from a 1:1 sex ratio can result in decreasing N_e and loss of genetic diversity in species with separate male and female sexes (e.g., not applicable to shrimp). The effective and census population sizes may appear stable. Selective fishing of a single sex (e.g., snow crab, lobster) can profoundly alter the sex ratio.
Selection differential	There is growing evidence that selective fishing has produced changes to life-history parameters such as age- and size-at-maturity. Assuming that variation in these quantitative traits is heritable, then these changes due to selective fishing may be irreversible. The selection differential is a measure of the evolutionary pressure induced by selective fishing practices.
Additionally for Sessile Marine Invertebrates	Sessile marine invertebrates are a special case as many are broadcast spawners and depend upon the proximity of a mate for fertilization success. The white abalone, a species near extinction, falls into this category.
Critical density (number/m^2)	It is important that the census technique is capable of detecting the actual number of animals per m^2. In many instances this will require the use of video surveys.

9.3.3.3 Respondent comments (Roger Doyle)

The genetics section of the workshop will focus on the conservation of genetic biodiversity in marine populations. However, genetics also offers various types of measurement that might serve as precautionary reference points (PRPs) for conservation at the ecological level. Dr. Kenchington and I thought that, as moderator of the genetics section, it might be helpful for me to mention some of these possible "non-genetic" applications of genetics. They are listed below in tabular form and I'll introduce them briefly at the workshop

A precautionary reference point is taken to be a measurement value which signals an unacceptable level of risk and which, if observed, triggers some management action that has been agreed in advance.

Column I in the table lists a genetic concept or sub-discipline; Column 2 lists a closely related ecological concept, or conservation problem, in the terminology of fisheries management; Column 3 indicates corresponding Precautionary Reference Points (PRPs).

Genetic Concept	**Marine Fisheries Management Concept**	**Precautionary Reference Points?**
(1) effective population size, N_e	***(1.1) endangered species status*** Warn of an incipient "extinction vortex" in a tiny population	PRPs: * critical loss of allelic diversity * significant single- and multi-locus disequilibria * extreme variation among year classes
	(1.2) actual stock size vs. VPA (1.2.1) Measure fluctuation in the real abundance of year classes (1.2.2) Check on validity of VPA and survey estimates	PRPs: * temporal changes in gene frequencies * microsatellite allele genealogies (coalescents) * microsatellite allele length-frequency distributions * multi-locus disequilibria
(2) mutation and gene flow	(2.1) migration patterns and natural stock boundaries vs. management boundaries	PRPs: * geographical mapping of gene-frequency discontinuities, clines and hybrid zones
	(2.2) selection of candidate marine protected areas (MPAs); "source-sink" functions of MPAs	* mixtures determined through genetic stock identification (GSI) procedures
	(2.3) disputed catches and transboundary issues	* GSI and forensic statistical analyses

Genetic Concept	**Marine Fisheries Management Concept**	**Precautionary Reference Points?**
(3) opportunity for selection; evolvability; genetic variation	(3) genetic biodiversity & conservation	PRPs: * minimum total allele diversity; genetic variation (several types of statistic available)
(4) ecological *sensitivities* and *elasticities* are equivalent to genetic *selection differentials* and *intensities* (This is quantitative genetics, not population genetics)	***(4) gear selectivity; catchability (q)*** Are fishing and management practices distorting the life history of a species?	PRPs: * Estimated from survey data and catch (VPA) data, *plus* a population dynamic model (e.g. surplus production or Beverton-Holt) , *plus* a genetic variance/covariance matrix
(5) coevolution	***(5) ecosystem stability*** Mutual effects of other species on the life history stages of a target species (e.g. size-specific predation)	PRPs(?) may be too difficult in a coupled system: * If not too difficult, they might be estimated as in (4), e.g. as coupled Lotka-Volterra models
(6) genotype assignment to a population	(6) enforcement (forensic identification of genotypes) (6.1) commercial catches from illegal sources (6.2) assigning responsibility for aquaculture escapes (6.3) assessing effectiveness of stock enhancement (6.4) CITES enforcement	PRPs: * minimal likelihood ratios and Bayesian probabilities which incorporate both genetic and non-genetic data

9.3.4 Objective #4: Exploited Species

9.3.4.1 Working paper (Paul Fanning)

Abstract

The monitoring programs for exploited marine species are discussed in terms of current practices, newly emerging practices and proposals for future work. The primary data sources are the fisheries statistics system, the commercial catch sampling programs and the research surveys. Each of these data sources provides information about specific aspects of the exploited species in question but they must be combined to obtain a complete picture. Fish stock assessments are the conventional, primary means of combining the individual data sources. The performance indicators are estimates of fish biomass and fishing mortality rates and the associated reference points such as $F_{0.1}$ and B_{lim}.

More recent approaches have been trying to broaden the information base being used in stock status assessments. New indicators include biological parameters (growth and condition), spatial distribution, predation, industry information and environmental effects. For these new indicators reference points and in some cases even the metrics are still a matter of debate. For data-rich examples with long time series of data, empirical reference points based on historical observations have been proposed.

Development of numerous and possibly disparate indicators requires that means to integrate them also be developed. A report card format has been put forward in which the indicators are presented in a single consistent list but the reviewer is left to apply their own interpretation and weighting to determine the overall stock status. Stoplight rules have been proposed in which management interventions escalate as the number of red lights increases, possibly with unequal weighting of the individual indicators.

While there are major monitoring programmes in place now, collecting many of the data required for the conventional indicators, some proposed new indicators will require either new programmes or enhanced data collection from the existing ones. Systematic collection of information on the views of industry participants is one area for a new programme while increased ecological and biological sampling from the existing surveys and commercial sampling activities may be adequate to address many other needs. The existing surveys, groundfish trawl and acoustic, are not suitable for some species, e.g. sharks and large pelagic fishes, and appropriate fishery-independent sampling of is required.

Introduction

The marine species, both finfish and invertebrates, that are exploited by directed fisheries have relatively long histories of close monitoring. The primary purpose of the monitoring has been to regulate exploitation, balancing economic wealth generation with conservation of the renewable resource. The data and analyses used in this monitoring have not, for the most part, been adequate to the purpose. We are all aware of the failure of fish stocks and centuries-old fisheries during a period when the greatest effort ever was being put into the task of monitoring, assessing and regulating them.

The primary data sources for monitoring exploited populations have been the fisheries themselves. Governments and other agencies have collected information to describe the economic performance of fisheries for at least 200 years in Canadian waters. During this time it was assumed that the wealth of the sea was inexhaustible. Only in the past 50 years or so has the collection of data specifically to monitor the status of fish stocks become standard. Increased data collection from the fisheries included biological information on numbers and age composition of the catch, growth and fecundity studies, tagging and migration studies as well as gear and catchability studies. Field studies in the 1950's and 1960's were supplemented in the 1970's with standardised annual surveys being adopted in most areas of Atlantic Canadian waters.

Dedicated surveys have become a central part of the monitoring of groundfish stocks, some pelagic stocks, as well as invertebrates such as shrimp, crabs and clams. In these, many of the biases intrinsic in fisheries-derived data either eliminated or controlled. A broader scope is available to incorporate both more detailed sampling of exploited species but also to obtain information on a large number of non-commercial species which occur in the survey catches.

One further source of data has developed in the period since the extension of jurisdiction in 1977 and that is from at-sea observers working on fishing vessels as they fish. These programmes were introduced as part of the compliance package on foreign vessels allowed to fish within the EEZ but they have also been routinely deployed on domestic vessels, particularly on the offshore industry vessels. Observers have also been integral to a number of science programmes collecting data from commercial platforms, either charters or co-operative arrangements.

The approaches and indicators routinely used depend on the amount and kinds of data available. In what has been considered the best-case situation, a fishery has a long history of catch data, possibly with the corresponding data on fishing effort, biological samples are regularly collected from the catch and the species is suitable for age determination. If all these hold, and a measure of stock size, e.g. a survey or catch per unit effort series is available, the traditional sequential population analysis (SPA) is the usual means of determining stock status. In cases when this is not possible, a variety of alternatives are used but are generally considered less rigorous and less informative. This view is being challenged as application of the precautionary approach leads to consideration of the impact of model misspecifications.

Regardless of the type of analysis and data sources, indicators or performance measures must have at least three key attributes. They must be measurable with a reasonable, and preferably estimable, degree of precision. They must be interpretable in terms of stock status, and they must be sensitive to changes in stock status with an adequate response time. All of these attributes are stated here in general terms and must be further defined in specific applications. A list of potential indicators (Table 1) has been compiled although not all of the entries possess all of the above attributes and only a subset of this list has been used to date.

Conventional Monitoring - Biomass and Mortality

Current Practice

Since the 1950's, the population dynamics concepts underlying the conventional monitoring practices have evolved relatively little. In spite of increases in complexity, improvements in estimation technique and additional information extracted by means of computer-intensive techniques, the principal means of assessing stock status remains a variation of SPA and the management objectives remain products of yield per recruit models. Sequential population analysis reconstructs the population of a fish stock from demographic, or population dynamic, considerations. By determining the numbers of individuals alive at a given time, the model can be used to infer the numbers alive at previous (or subsequent) times by accounting for the intervening mortalities.

The process begins with estimation of the total numbers at age removed from the population by the fishery, giving these models their more general name of catch-at-age analysis. Three pieces of information are routinely used to construct the catch at age, these are the total catch in biomass, the length and age composition of samples from the catch and the average weight at age in the samples. The catches (and corresponding fishing effort) are recorded by the fisheries statistics system, which also conducts the quota monitoring required by the management system. Historically the statistics system operated with regional and area statistics staff recording the landings. This has evolved over recent years to be almost entirely operated by third-party companies providing dockside monitoring services to the fishing industry. All of the remaining, biological, data are obtained by a network of samplers operating at the fish landing sites. As with the statistics, what was once entirely an operation of the DFO, now includes samplers working for the fish processors and other industry groups.

Once a catch at age has been estimated, it can be used to account for the fishery-induced mortality, at least the fraction represented by the landed catch. The remaining mortality sources are usually lumped into a single source, assumed constant for all age groups and for all years. Now it remains to fix the population size, for each yearclass of fish in the stock. For this a consistent time series of stock abundance data is required. Initially the catch per unit effort in the fishery was assumed to be a constant function of the abundance of fish, however, that has been dropped in favour of fisheries-independent indices of abundance, primarily surveys. In current assessments the tuning index, whichever it may be, is used to define an objective function, typically least-squares or maximum-likelihood, and initial population numbers for the SPA are optimised. The calibrated SPA provides a matrix of numbers at age by year, associated fishing mortality rates and, when combined with mean weights at age, the population biomass at age (Fig. 9.3.4.1.1).

The two primary, and in many ways the only, performance measures utilised to date from these assessments are the stock size, usually as spawning stock biomass, and the exploitation rate or, equivalently, the fishing mortality rate. The reference points for each of these have been considered in ICES, NAFO, Canada, and numerous other fora and can be considered well defined (Fig. 9.3.4.1.2) The third product of these assessments is recruitment to the stock, i.e. production of juveniles, however in spite of an obvious value (Fig. 9.3.4.1.3) there are few applications of this performance measure and little work on appropriate reference points for recruitment.

Emerging Practice

The catch at age analysis is dependent on, and integrates, three essentially independent data sources, namely commercial catch statistics, biological catch sampling and research surveys. Recent work on the application of the Precautionary Approach has provided some impetus to using these sources more independently, to examine the standard model assumptions and suggest alternative performance measures. The research surveys provide, as empirical observations, estimates of relative numbers at age, collected in a standardised manner every year at the same time. From these data it is possible to compute biomass indices, including spawning stock biomass, recruitment indices and total mortality rates (Fig. 9.3.4.1.4, 5 and 6). Because all the measures are relative, related by an unknown, but assumed constant over time, size-specific function, the reference points applied to the SPA-type of estimates are not applicable. To date reference points have been picked as arbitrary functions of the time series of available observations. This was deemed reasonable when a long and consistent series gives good indications of the dynamic range in the indices. This is obviously not feasible in cases of new or significantly modified surveys.

Biological monitoring

Current Practice

A number of strictly biological parameters are monitored, some as part of the data collection described in the preceding section and others collected independently of the population dynamics monitoring. In the first of these categories, is the size and age composition of the population. This is derived from surveys so again, the measures are relative, subject to the sampling biases, i.e. catchability, of the survey gear. While this indicator is measurable and sensitive, there are problems with the interpretation. For example, an age distribution over-weighted with young animals may indicate exceptional recruitment, generally a positive indication, or alternatively, it may indicate very low adult survival, a dangerous condition. Considerable additional information is required to interpret this indicator.

The biological productivity of individual fish is reflected in their growth and condition and is in large measure independent of the population dynamics indicators. As with most of the biological indicators, it is difficult to interpret without additional information. In spite of that difficulty these indicators may be amongst the most sensitive with fish condition capable of responding to changes in productivity within a single year. Reference points have not been established but current performance can be compared with historical averages when a long time series is available (Fig. 9.3.4.1.7 and 8).

Emerging Practice

Recent stock status assessments have considered the areal distribution of the stock as an indicator. A number of metrics have been considered but none have been adopted or ruled out yet. In all cases they are based on the survey observations and two examples are the proportion of non-zero sets in the survey (for a given species) and the area occupied by a fixed percentile e.g. 75%, of the stock biomass. Interpretations are unsettled so far but the spatial responses appear to be sensitive and measurable, at least for some species.

Proposed Indicators

The stock reproductive potential (SRP) has been proposed (Trippel, 1999) as one alternative to the traditional spawning stock biomass. This approach accounts for effects of age and size differences in specific fecundity, spawner experience, fish condition and other factors as it attempts to provide a more sensitive and accurate representation of the ability of the stock to produce recruits.

Environmental/ Ecological

Emerging

To date the immediate effects of environmental conditions on fish stock status have not been explicitly described. Instead, there is an assumption that temperature affects both somatic growth and reproduction and hence harsh environmental conditions will lead to reduced productivity. That being the case, the environmental effects may be appearing as reductions in condition or size at age or stock reproductive potential, or all of them. Thus environmental conditions may be useful as the type of ancillary information required to interpret changes in other indicators such as the biological parameters.

Proposed

Ecological indicators such as predator or prey abundance have been suggested but to date no useful indicators have been proposed. In spite of this, there are management regimes (CCAMLR and US North Pacific) in which specific consideration for predators is made when allocating total catches.

Fishery monitoring

Emerging

The traditional monitoring of fisheries has been to collect catch and effort statistics, particularly as applied to quota monitoring for management purposes. The routine uses of these data were described above but there are also direct empirical uses for these data such as spatial distribution of catches or fishing effort or trends in catch per unit of effort.

An important additional element is the amount and fate of by-catch taken incidental to the directed species. While some by-catch is landed as part of the commercial catch there is also a considerable amount of catch that is returned to the water, usually dead, as discards. Estimates of discards by species are usually only available from at-sea observers although some shore-based methods of estimating discarding of undersize fish from commercial species have been developed recently (Allard and Chouinard, 1997).

Systematic consultation with fishers on their perceptions of the recent trends in biomass and recruitment provides an opportunity to gain detailed information but care must be taken to ensure that broad representation by gears and areas fished is obtained. Fishers tend to have very detailed knowledge pertinent to their own experience but little means of integrating it to the stock level. Telephone surveys, designed with the assistance of Statistics Canada have been used in the Gulf Region for several years and confidence in the approach is growing.

Proposed

Compliance of the fishers with regulations such as the discard limits, size limits and reporting requirements has been proposed as an indicator of stock status on the assumption that compliance is higher when fish are more abundant.

Integration

The appropriate means of integrating these indicators into a coherent stock status assessment remains to be defined. Considerable effort is going into this issue in DFO, the FRCC and many other fora.

Score Cards/ Report Cards/ Stoplights

In the several recent Regional Assessment Process meetings the stock status indicators have been presented in report card format listing the individual indicators but not attempting to specify a single overall rating (Table 2). This is obviously an incomplete treatment until experience develops and consensus is reached on appropriate ways to complete the integration.

Precautionary Approach

One element of the precautionary approach is that when reference points are triggered a set of pre-agreed decision rules takes effect. One of the original proposals for the stoplight approach (Caddy, 1998) suggests escalating restrictions on fishing effort as more indicators turned yellow or red.

Table 9.3.4.1.1. Proposed indicators of stock status to monitor exploited populations of fish and invertebrates. Not all indicators are available or applicable to all species.

Indicator	Reference Point	Interpretation	Metric
Population Dynamics Indicators			
Biomass (total over specified ages)	B_{lim}, B_{buf}, B_{tr}		B_{a+}, biomass in given age range
Exploitation	F_{lim}, F_{buf}, F_{target}		F_{fr}, fully recruited F
Recruitment			N_a, numbers at early age e.g. 1
Survey-based Indicators			
Biomass index			age/length based CPUE in kgs
Recruitment index			age/length based CPUE in num.
Total Mortality (Z)			annual or smoothed Z's
Biological Indicators			
Condition factor	Compared to historical series	low condition can be due to either high density effects or poor environment	Predicted weight at a given age
Age structure	Compared to historical series	low diversity usually from truncated age dist^n	Age diversity or interquartile range
Size structure (maturity?)			
Geographical dist.	Compared to historical series	population reductions often reduce size of occupied territory	area occupied by given quantile of survey catch
Growth rates			
Environmental and Ecological			
Environmental regime	Compared to historical series	severe temperature regime can reduce growth, reprod. and survival	proportion of RV sets in 'preferred' temperature
Fishing Industry Indicators			
Fishers reports on recent biomass trend		Industry perception of trend in status	positive or negative indication
Fishers reports on small fish abundance		Industry perception of trend in recruitment	positive or negative indication
Geographic range	Compared to historical series	population reductions often reduce size of occupied territory, fishery may be driven by management considerations	area occupied by given quantile of commercial catch (possibly by statistical unit)
Over/under quota	TAC	failure to reach quota may indicate overestimated abundance, can be confounded by management measures	percent or absolute deviation
Fishery Management Compliance			
By-catch impact	Proportion of directed F??	impact of other fisheries on mortality of given stock	Bycatch partial F?
Size regulation	Compared to historical series	may indicate recruitment	Frequency and distribution of small fish closures
Unaccounted mortality	Proportion of directed F??	impact of other unreported catch or M on mortality of given stock	Discard partial F?, Change in M?
Habitat impact	Compared to historical series	loss of identified spawning or other obligate habitat may reduce survival or reproduction	proportional area of impacted habitat
Quality of statistics reporting	Fully described and accurate statistics for fishery, bycatch and discards	errors in statistics will increase uncertainty and cause precautionary reduction in harvest levels	subjective confidence assessments and estimates of required adjustments

Table 9.3.4.1.2. 4VsW cod example based on assessment results from 1998 assessment.

Indicator	Metric	Target	Limit	Status	Comment	Figure
SPA Biomass ('97)	B5+	70.	42.	Red	Retrospective pattern	1
SPA F	F7-9	0.2	0.4	Green		2
SPA Recruitment	N1	91 Mill	55 Mill	Red	Also for age 3	3a,b
RV Biomass Index	B3+	61	36	Red	Red since mid 80's	4
RV Recruitment	N3	8.8	5.3	Red		5
RV Z	Z4-6	.80	1.12	Red	Also for ages7-9	6a,b
Condition Factor	CF?	454	272	Green	Scaled to emphasise change	7
Growth Rate	G(4-6)	.15	.09	Yellow	Noisy	8
CPUE Index					N/A	
Fraction of non-zero sets		39%	23%	Yellow	Needs work on limits	9
Area of 75% abundance	A75%	4.4%	2.6	Yellow	Needs work on limits	10
Overall				Red		

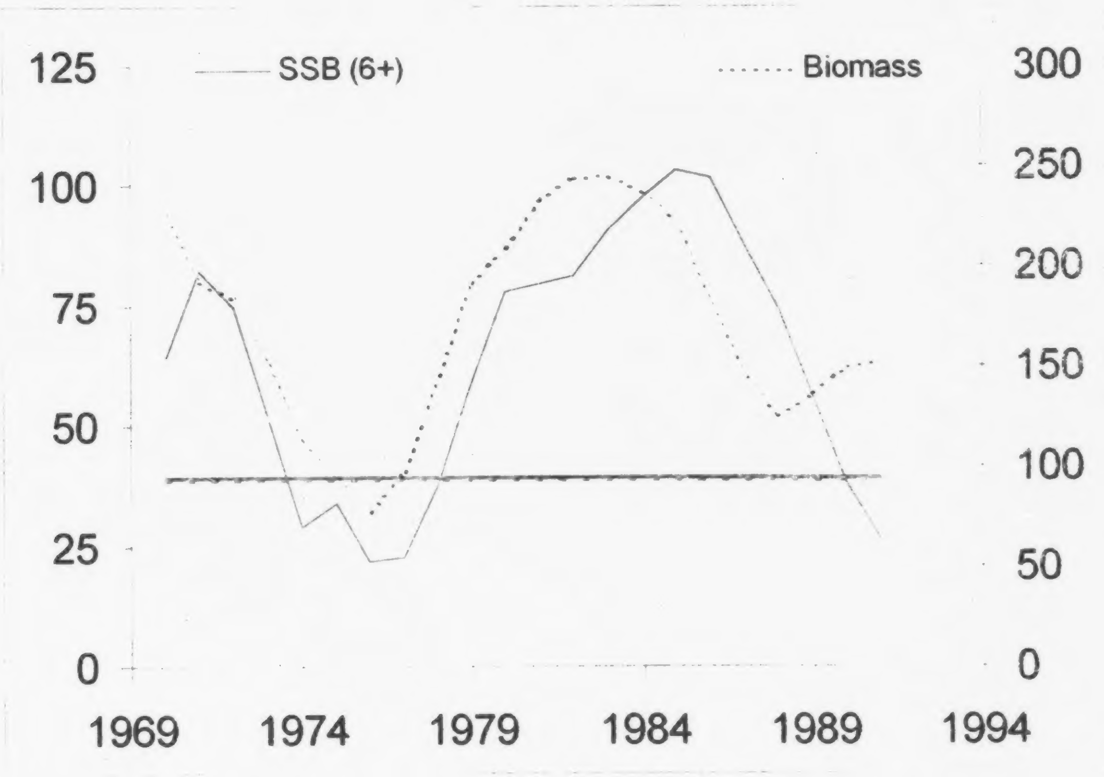


Fig. 9.3.4.1.1. Example assessment results for 4VsW cod

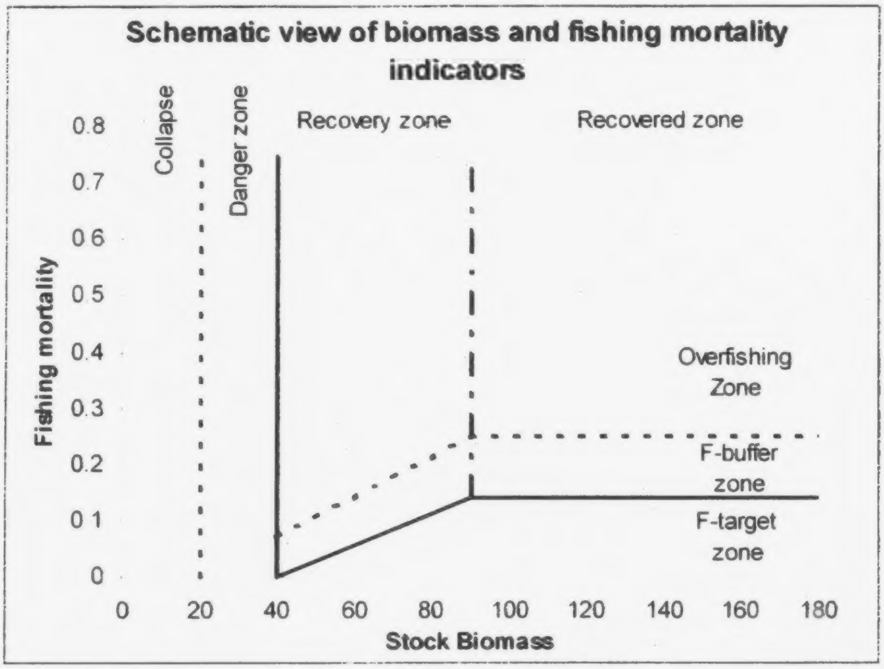


Fig. 9.3.4.1.2. Schematic of F and B reference points.

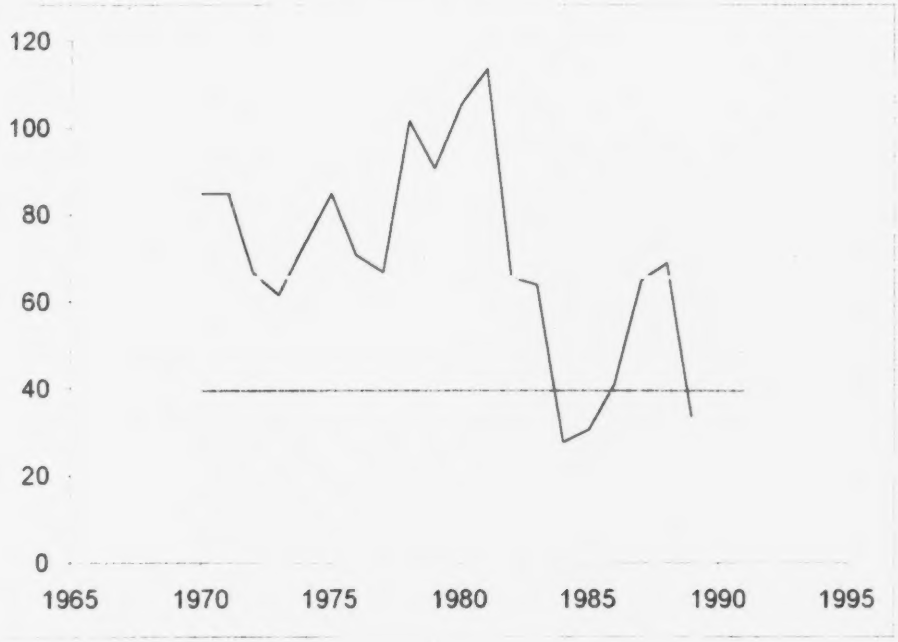
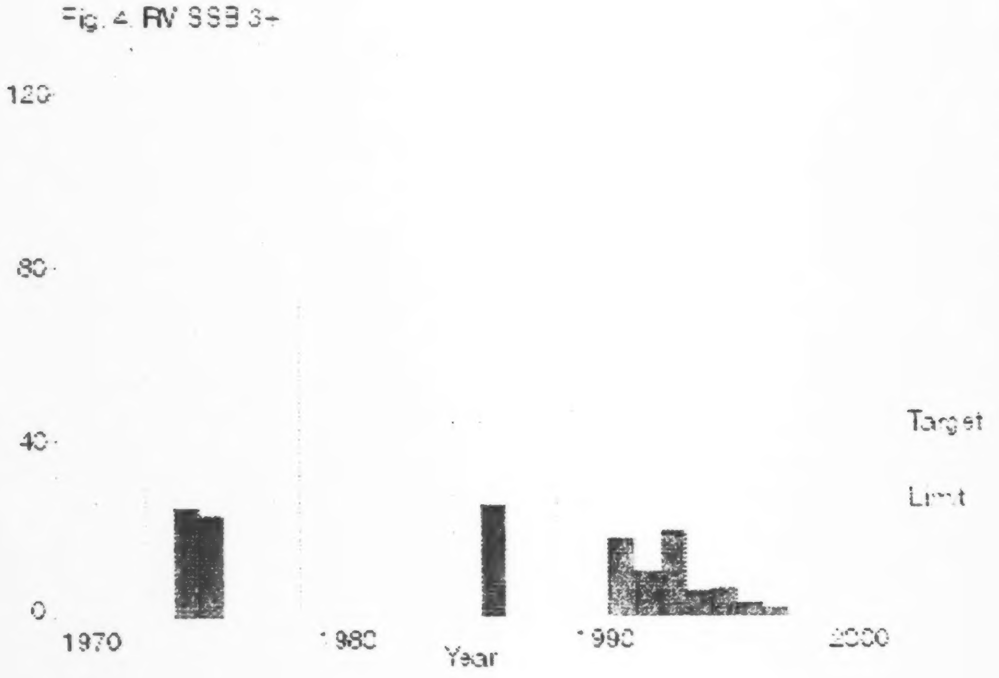


Fig. 9.3.4.1.3. Recruitment index



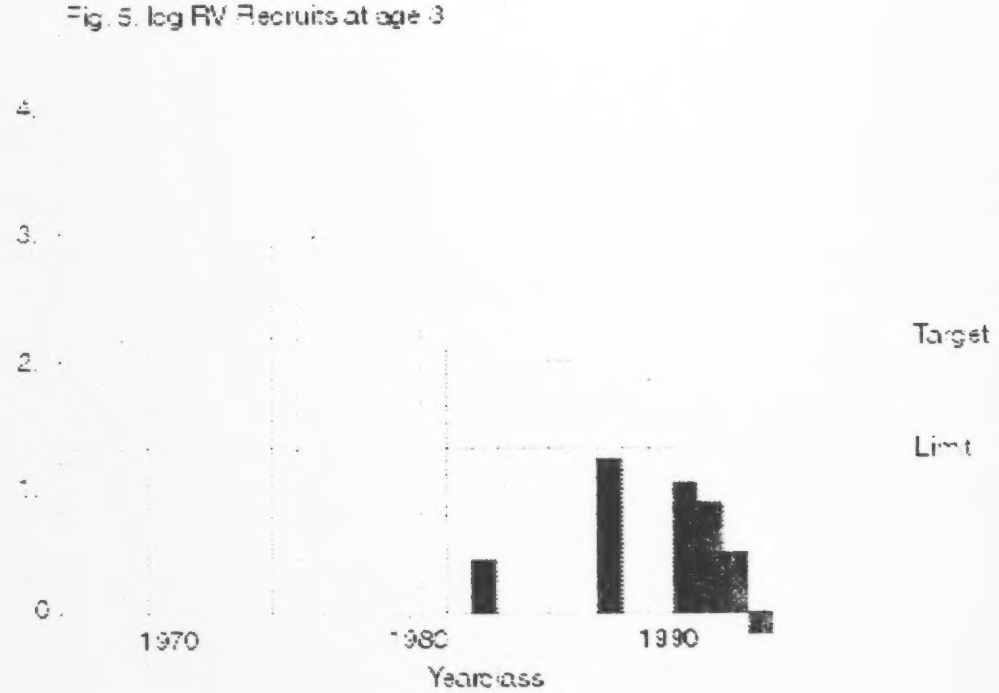


Fig. 9.3.4.1.4 and 5. Research survey indices of biomass and recruitment with empirical reference points based on historical time series.

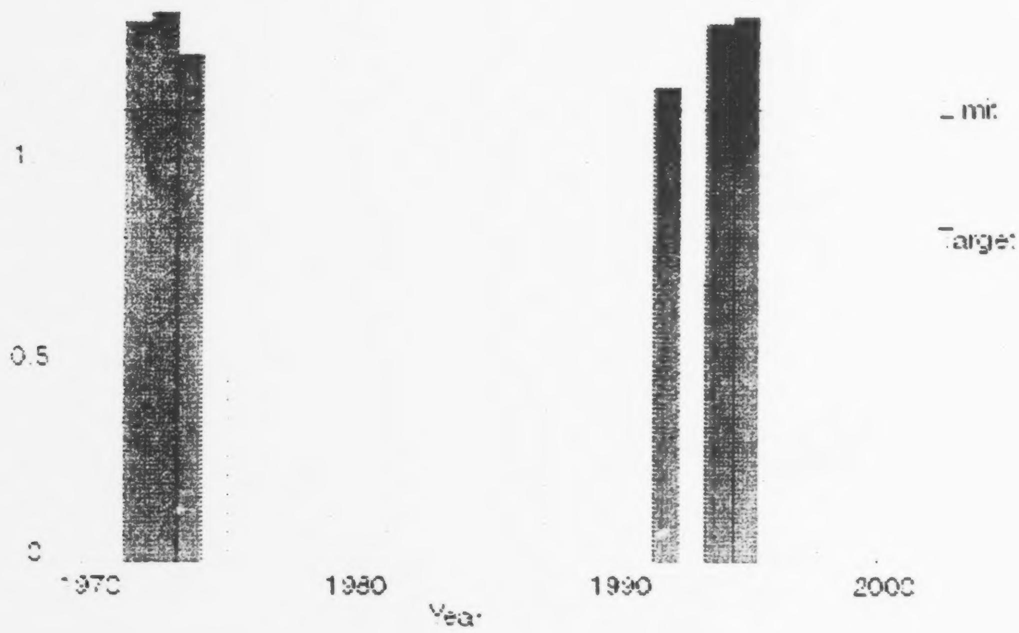


Fig. 6a. RV Z average over ages 4-6

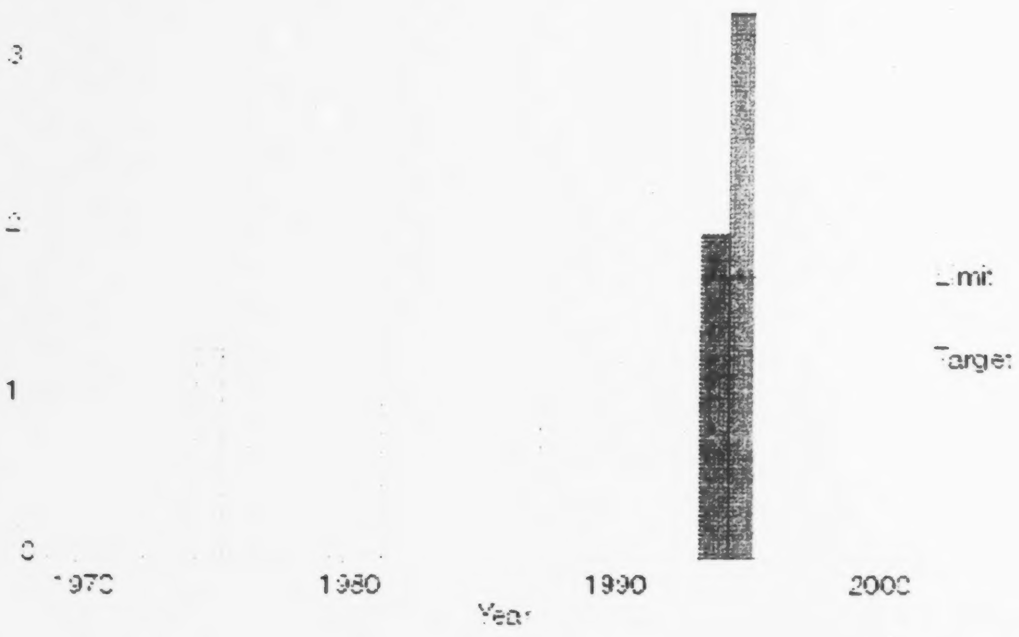


Fig. 6c. RV Z average over ages 7-9

Fig. 9.3.4.1.6. Research survey estimates of total mortality

Fig. 7. Scaled condition factor

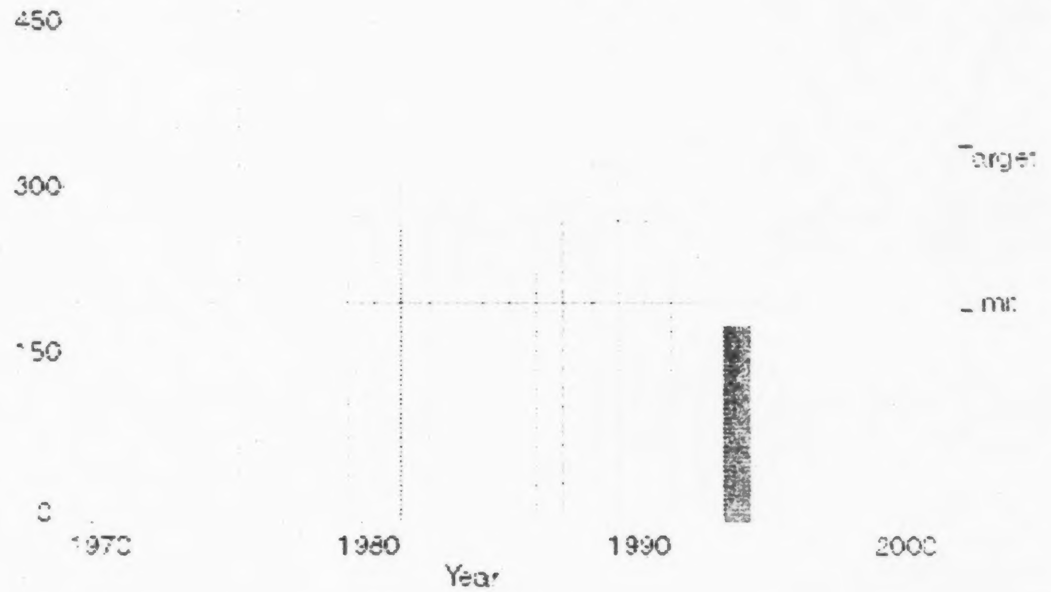


Fig. 8. Growth rate average for ages 4-6

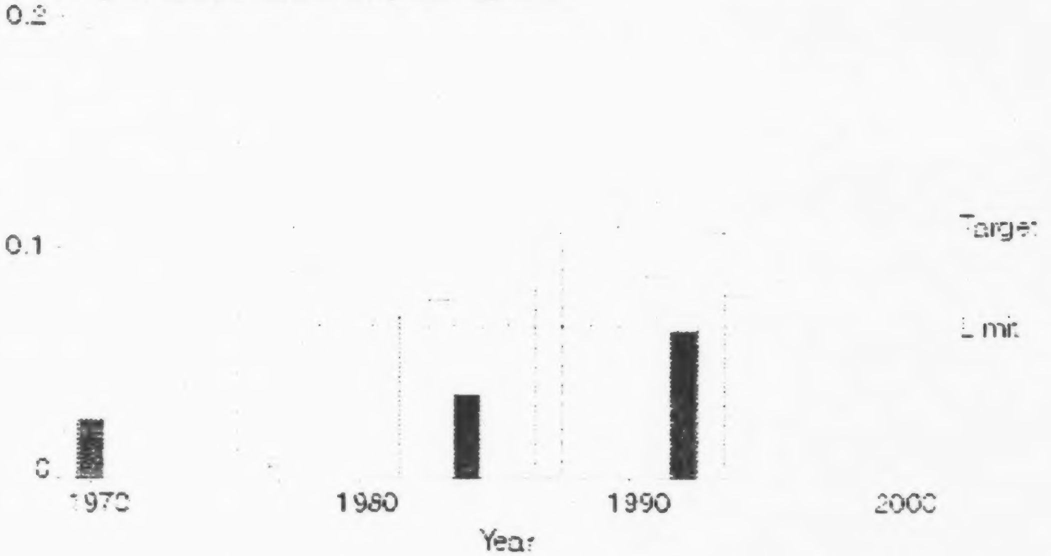


Fig. 9.3.4.1.7 and 8. Fish condition and growth rate estimated from research surveys

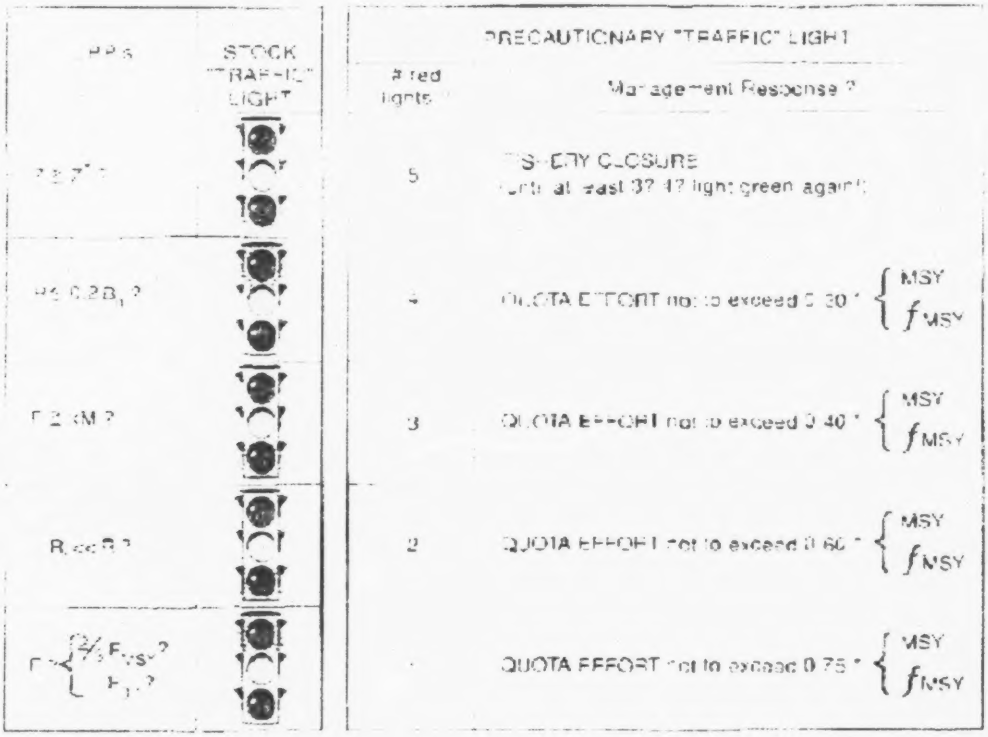

STOCK "TRAFFIC" LIGHT
PRECAUTIONARY "TRAFFIC" LIGHT
# red lights
Management Response ?
5
FISHERY CLOSURE
(until at least 3? 4? light green again!)
4
QUOTA EFFORT not to exceed 0.30 * MSY f_{MSY}
3
QUOTA EFFORT not to exceed 0.40 * MSY f_{MSY}
2
QUOTA EFFORT not to exceed 0.60 * MSY f_{MSY}
QUOTA EFFORT not to exceed 0.75 * MSY f_{MSY}

Fig. 9.3.4.1.9. The Caddy stoplight proposal for integration of multiple indicators of stock status and application in the precautionary approach.

9.3.4.2 Respondent comments (Jean-Claude Brêthes)

What is our monitoring task?

This presentation is made on the light of the LMR-GOOS workshop, *i.e.* to answer the questions: how to monitor a harvested resource? And, related to the previous one, what should be monitored? We have to set a diagnosis of the resource (independently to management issues) and to situate its status somewhere between two extreme levels, extinction and "pristine state". With the exception of long living species, or low fecundity species, fishing rarely brings a harvested species to extinction ("commercial extinction" happens before), so we try to define a crash zone, where the probability of stock's recovery becomes very low. We cannot know what was the pristine state (as we started the studies well after the beginning of the fishing activity), so we define a "healthy" zone from the best of our knowledge, based either on models or on reasonable assumptions. We are looking for indicators that should give a picture of the current state, able to track variations and that could lead to probabilities of future trends.

What is done at the present time? Fisheries science is using fish dynamics models, which provides two basic, easily understandable indicators, fishing mortality (*F*) and biomass (or Spawning Stock Biomass, *SSB*), which can be obtain from various sources, from surveys to analytical assessment (Sequential Population Analysis). We can then plot the graph, becoming classical, of *F vs SSB* and define various cases of stock status. *F* is there used as an indicator as well as a "control factor". There is a consensus now that those two indicators are not sufficient to capture the trends in the fisheries system, especially as we tend to move to ecosystem based management.

We can broaden the basic concept while adding elements (Fig. 9.3.4.2.1). Precautionary Approach implies two basic elements: protect the resource base (i.e. biomass, which might include recruitment levels) and protect the reproductive capacity of the resource: it is basically the spawning stock biomass, but it also means keeping a wide age structure (older fishes are better reproducers) and the genetic diversity. All those elements can be part of the "richness" of the population. Stress factors put the richness at risk among them fishing mortality being the main one, but others have to be considered (physical environments, predators and prey abundance), as well as human factors (*e.g.* compliance to regulations). The basic task is the monitoring elements of richness and stress (risk) factors

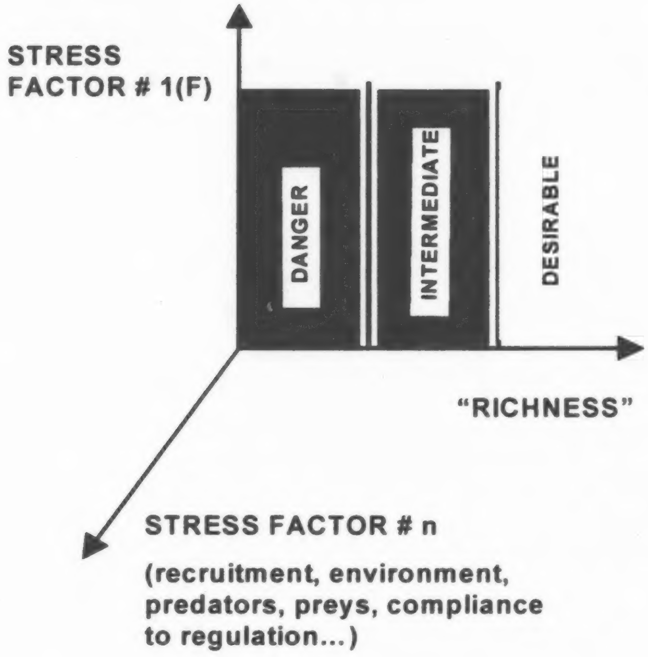

STRESS
FACTOR # 1(F)
DANGER
INTERMEDIATE
DESIRABLE
"RICHNESS"
STRESS FACTOR # n
(recruitment, environment, predators, preys, compliance to regulation...)

Fig. 9.3.4.2.1. The monitoring of an exploited stock involves monitoring elements of "richness" (biomass, recruitment, age structure...) and sources of risks.

Indicators

Several indicators of "richness" can be used, or imagined. Paul Fannings presents criteria to identify key indicators, they won't be repeated here. Basic principles can be to remain simple and practical: indicators should reliable (be able to track trends), measurable (at a reasonable cost), and relevant for the system involved (sediment structure is more relevant for benthos then for demersal fishes, to caricature). In several cases we have to use proxies (Fig. 9.3.4.2.2).

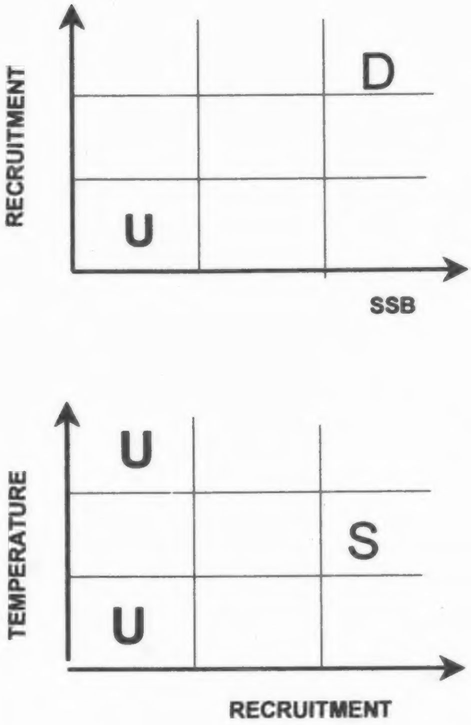


Fig. 9.3.4.2.2. Examples of possible approach - A recruitment-stock relationship is now commonly divided into sectors where probability of good recruitment is greater: U=unacceptable sector; D= desirable sector. We can use the same approach for other indicators: temperature may be detrimental for recruitment either if it is too low or to high; S= satisfactory.

How to use indicators?

A list of indicators creates a multidimensional model. Several ways to treat this model can be suggested. A simple approach is the use of a "report card" (or "performance report") which lists indicators, targets, limits and current value (cf Section 9.3.4.1). Each indicator's value can be ranked with a "traffic light system" (red is bad). A further step is to give a weight to each indicator (most relevant and most useful will get a higher weight than others: SSB and fishing mortality are obviously in that category). A step even further is to transform the indicator value in term of "score", related to the target value (the target value can be "0" and the limit of unacceptable situation a "1"; the reverse is also possible!). With that approach, it seems possible to incorporate quantitative "hard" values (biomass) or ordinal indicators, or even qualitative information. A proposed tool to visualise the situation is the "radar plot" (Fig. 9.3.4.2.3): it represents a global picture of the stock and the weaknesses that should be addressed (or used as a "flag": temperature, for instance).

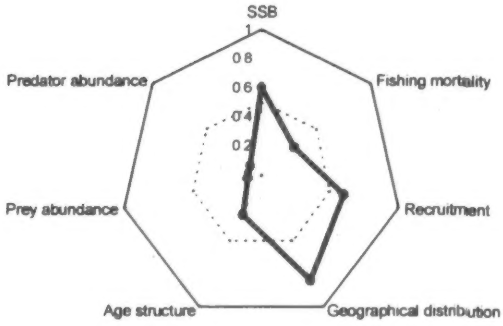


Fig. 9.3.4.2.3. Theoretical example of "radar plot". The value 1 represents the unacceptable situation while the centre is the target; the dotted line represents the limit between the target zone and the danger zone; along each radius is placed the "score" of each indicator. In that theoretical example, Biomass, recruitment and geographical distribution are of concerns.

Do we know enough?

The common answer is "no". The question would be: how much is enough? The issue is to decide if we can draw a reasonable view of the situation with the current available information. In fact, and at least for most groundfish stocks, we have a large amount of data. A subsidiary question would be: can we do better with what we have? My feeling is "yes".

Taking advantage of the accumulated knowledge also means considering the "social" (ethno-scientific) knowledge. While scientific tools are good to track and monitor long term trends at a large scale, fishers are able to provide information at the scale of their daily activity, i.e. to track small scale (time and space) variations (Fig. 9.3.4.2.4), and, sometimes, to situate those variations on a general historical perspective: spawning areas and periods, inshore patterns... The problem is to make this knowledge usable. We have to gather, organise and treat information from various origin and of various qualities: quantitative but punctual, semi-quantitative and qualitative. Information can be given for different purposes and may not be "objective", in the scientific sense. Social scientists are to be required to help in that matter.

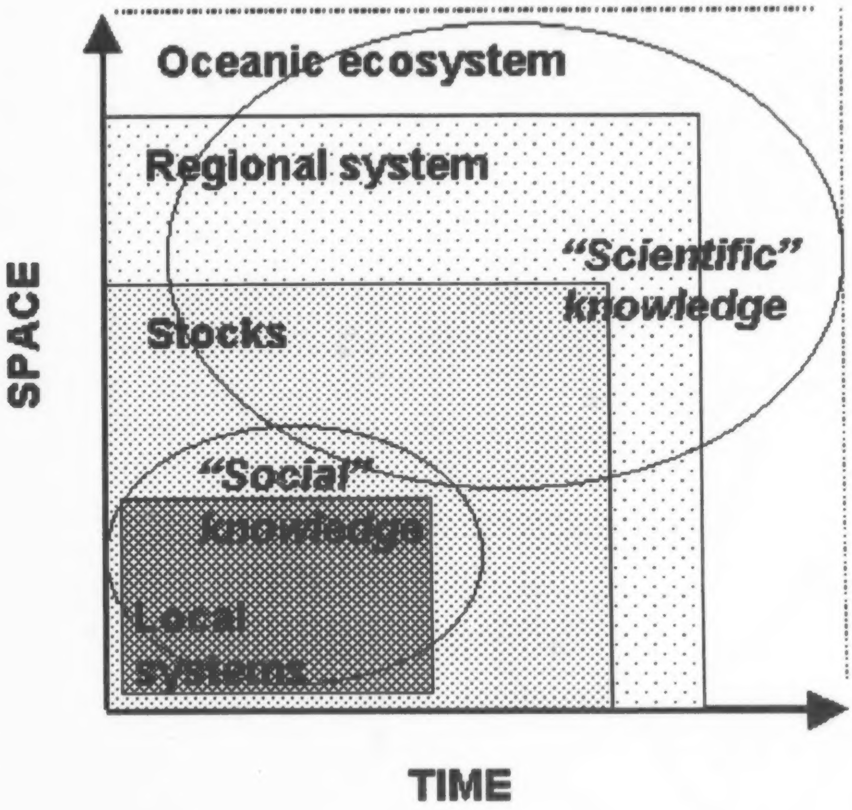

Oceanic ecosystem
Regional system
"Scientific" knowledge
Stocks
"Social" knowledge
Local systems...
SPACE
TIME

Fig. 9.3.4.2.4. The different scale of perception of the fishery system between science and fishers.

Summary

We aim at getting a global vision of a resource status, including biological parameters and environmental parameters. We then face several challenges, among them:

- Which data do we use? Do we need more? How much is enough?
- How can we approximate with enough reliability the current status with the current knowledge?
- How can we set targets and limits?
- How do we treat a multidimensional system in order to give a coherent usable picture?
- How can we use efficiently the "social" knowledge?

And certainly others...

9.3.5 Objective #5: Non-exploited Species

9.3.5.1 Presentation – outline (Bob Mohn)

Introduction.

The status of non-exploited species is generally more difficult to estimate than those that are exploited. The first problem is the absence of commercial information which is useful in scaling indices to absolute values as well as the biological sampling that is often available. Secondly, because they are often of less economic interest, they are less likely to be surveyed. These two sorts of information are the keys to most stock assessments. The potential roles of non-exploited species are reviewed, followed by performance indices based on the roles. Commonly used models are then presented. The presentation will be illustrated with several examples, principally of monkfish, cod-seal, groundfish-skate and Antarctic krill systems.

Roles within ecosystem (relationship of Non-exploited species (NES)to exploited species)

1. NES is independent (Monkfish)
2. NES is by-catch (skates - groundfish)
3. NES is prey (Sandlance - Cod)
4. NES is predator (whale - krill, seal - cod) (distinction of whether NES is important)

Types of observations (performance indices)

1.Direct survey of NES
    a. abundance index and its derivative
    c. geographic structure (distribution)
    d. biological structure (length dist. , age dist, condition…)

2. Indirect indices for NES
    a. NES is prey
        - functional response of ES (health, condition)
        - ?
    b. NES is predator
        - functional response of ES (survival, recruitment)
        -. inferential from ES (stomachs, scats, "signatures")
    c. NES is independent
        - analogy (canaries)

Review of models

1. Single species
    a. relative abundance; catch curve variants
    b. absolute abundance (mostly production models -> likelihood variants)
2. Two species
    a. dynamic
3. Multispecies
    a. balance
    b. dynamic

Synthesis

1. How much do we want/need to model (Expansion of minimum realistic model concept)
2. How much to we want/need to measure to build such models

9.3.6 Objective #6: Emergent Ecosystem Properties

9.3.6.1 Working paper (Jake Rice)

Introduction

There are many inventories of metrics of community and ecosystem status; review articles and even books on them. Among the classics are Gauch 1982, Pielou 1984, and Jongman et al. (1987), with more recent ones including Spellerberg (1991), Warwick and Bayne (1993) and Patil et al. (1993). Rather than simply give another compendium of what sorts of metrics are out there, I want to first consider why we would have such a class of metrics in a workshop on monitoring living marine resources. I can think of three possible reasons

- Because everyone else does
- Because they are useful for communicating the state of the ecosystem being monitored to other specialists and non-specialists
- Because they are useful for detecting changes in the state of the ecosystem being monitored.

The first of these is a silly reason to do anything, particularly in a period of limited funding and time. However, in discussing plans for ecosystem monitoring programs in some international fora, it seems to reflect most accurately the thinking behind the inclusion of ecosystem metrics in monitoring programs. I won't address it further, but we should keep in mind that if we cannot justify the indices on other grounds, they should not be part of our program just because "the ecosystem" happens to be in fashion.

Communicating information on the state of the ecosystem is an important task, and there are many clients for this information. Some of the clients are other professionals in our field. As a community of scholars, we have learned in our university studies how to interpret core indices of diversity, richness, etc, as well as axis from major ordination methods. New indices proliferate, and only a tiny fraction of researchers can remain current in them all. Nonetheless, as long as publications and reports from the monitoring program contain a few good references or a suitable methods section, professionals can communicate among themselves using almost any of the hundreds of metrics of ecosystem status.

The situation is very different when communicating to non-specialists, including decision-makers and policy-setters from less computationally intensive backgrounds, resource users, and the general public. The fact that Canadians consistently tell pollsters that they give high importance to biodiversity does not mean that they are prepared to interpret correctly Hill's N1 and N2, or other members of the suite of community metrics, if this is the only information they are given. Even if they are given a suite of complementary metrics, so they have the information necessary to see the degree to which richness, evenness and dominance characterize a system, few will grasp the nuances behind the values of the various metrics. When the metrics are accompanied by appropriate explanatory narrative, many non-specialists can grasp a great deal about the status of complex ecosystems. However, I argue from experience that it is the narrative that actually does the communicating, and not the metrics that the narrative accompanies.

There is a communication problem at a more fundamental level, however. All of us in fisheries know well the drawbacks, in fact, in getting clients focused on "the number", instead of the bigger picture which they should consider in forming their views. If this obsession with "the number" is problematic often in single-species assessment and management contexts, it can only be more problematic in the more complex ecosystem cases. Even if the general public or decision-makes were to be well educated about the information content of metrics of community or ecosystem status, providing them with the metrics but not the accompanying narrative does not give them the information they need to understand what is happening, engage in informed discussion of options, and decide to implement appropriate remedial measures. Saying that richness has decreased without saying which species have been lost is not giving the clients the information that they want or need. Nor is saying that the community has moved further into a marginal position in Correspondence Analysis space or to an area of faster throughput in an ecosystem model, without describing what characterizes both the area enter and the space previously occupied by the community. Even worse, showing that a diversity index has decreased, when the cause is that a strong year-class has recruited to an abundant stock, is mis-information that may prompt wrong reactions. Given the species list or narrative on ordination or modelling space needed to interpret the metrics, the metrics themselves become superfluous to the communication.

This argumentation leaves one reason for including ecosystem metrics in a monitoring program; they are useful to professionals for detecting change in status of the ecosystem. This need will structure the rest of my talk. First I address what properties a sensitive metric would have, and how to judge if a metric is likely to possess those properties. Then I summarize very briefly the classes of ecosystem & community metrics, drawing from a lengthy review done last year. The core of the paper is evaluating which classes or members of classes of metrics are likely to measure up well as usefully sensitive metrics of ecosystem status.

Properties of usefully sensitive metrics

Sensitive metrics will change value substantially when the status of the ecosystem changes and stay relatively stable when the ecosystem is not undergoing large changes. Also, unless they are binary metrics they will have a monotonic relationship with the properties they supposedly reflect. Furthermore, even if the scale is not exactly interval over its entire range, it is desirable to have the index not be highly differentially sensitive to change at different positions along the scale. Otherwise, past experience becomes an unreliable guide to interpreting whether a change in the index of any given size reflects a major ecosystem perturbation, or a minor ecosystem flutter.

Many of these properties are characteristics of any good signal; in most cases a signal of ecosystem change, because absolute values of the metrics are rarely informative in themselves.

(An SSB of 50,000 t is much more concrete than a H' value of 2.73, or CA score of 37.) In psychology, there is fully developed theory of signal detection, and the framework used to evaluate performance of both the signal and the person monitoring the signal will be useful for our evaluation of ecosystem metrics as well. A good signal – in this case a good indicator of ecosystem or community status or change - is a signal which has a high hit rate, with low rates of misses and false alarms. In ecological terms, a high hit rate means that when the ecosystem undergoes a change which should be of importance to the science and management communities and to clients and general public, the metric will show a substantial directional change as well. Misses correspond to cases when there is an "important" change in the ecosystem but the metric does not change enough to attract attention. Conversely, false alarms would correspond to cases when the value of the metric changed enough to prompt management action, but the ecosystem itself was only varying within its normal range. Although true negatives often are not considered in formal signal detection theory, they show the expected logical features – stable values of the ecosystem metric over a period with there was no marked change in the state of the system. In the material that follows, the various classes of metrics will be considered in the context of rates of hits, misses and false alarms.

One other good point about this signal detection framework – it allows the assymetry of costs of the two types of errors to be addressed. In human health issues, many false alarms are tolerated, to ensure there are almost no misses. In natural resource management, the assymmetry of costs depends on ones role. Environmental activists may favour the human health strategy; and tolerate lots of false alarms to ensure ecosystem conservation action is always prompted when needed. An industry suffering many reductions in harvesting opportunities when there is no ecological need may have quite a different view.

Classes of metrics

Rice (in press) summarized four categories of ecosystem metrics. The first two classes, indices of diversity and ordination techniques, are distinct and widely recognized, often referred to as univariate and multivariate metrics, respectively. These titles reflect the conceptual difference between the two classeses of metrics. Univariate indices distill all the information being considered into a single number, whereas multivariate metrics represent the total information in geometric or linear algebraic simplifications of complex data sets. These simplifications, although much less complex than the original data matrices, are still ordinations of individual sites and species in a multidimensional space.

The conceptual boundary between the third, summary properties of ecosystem data, and the fourth, measures of "emergent properties", may be less clear. They are much more clearly differentiated by how they are calculated than by the information they try to represent. Summary properties of ecosystem data sets are closely tied to the data themselves, simply aggregating the available data according to some rules. The emergent properties of ecosystem models may use the same data, but superimpose functional relationships structured into ecosystem models. Often the model formulations have as much influence on the metrics as the data themselves do.

Univariate Diversity Indices

Description: Although measures of what is now called the diversity of ecological communities were proposed more than 50 years ago (Preston 1948, Simpson 1949), to most ecologists the paper by MacArthur and MacArthur (1961) was considered seminal. In the following decades indices of diversity proliferated freely. Two key papers in the early 1970s (Hill 1973a, Peet 1974) tried to bring some structure to the diversity of diversity indices. Hill, in particular, highlighted that diversity is a joint construct of both how many species are present in a collection (richness), and how similar their abundances are (evenness). Many of the indices vary only in the relative weight given to richness vs. evenness. Some indices additionally try to emphasize the role of most important species in a community (dominance; McNaughton 1967). The ecological and mathematical theory behind indices of diversity is treated in relatively unified manners in Pielou (1984) and Magurran (1988).

Evaluation: In trying to collapse all the information on species richness and relative abundance in a single number, any individual index of diversity can be misleading in (at least) two ways. Two communities with very different numbers of species can have similar estimated "diversities", if the distribution of abundances across species is also differs in corresponding manners (i.e. the richer community is more dominated by the more common species). Alternatively, two communities that generally are quite similar in all their common species can still have quite different estimated "diversities", if many rare species are recorded one of the communities, whereas few are recorded in the other.

This unspecificity of diversity indices means that both misses and false alarms will be relatively common with diversity indices. Whole ecological guilds can be reduced greatly in abundance, with major trophodynamic implications. However, as long as some other guilds, perhaps at the next trophic level, increase so the mix of abundant, common, and uncommon species is similar, diversity indices may not register a noteworthy change. On the other hand, very strong recruitment of even a single species can greatly reduce evenness, and hence diversity indices which give weight to evenness. This sends the false alarm that diversity has suffered, when the ecosystem change is just a recruitment pulse.

These misses and false alarms are not insurmountable problems to application of diversity metrics in ecological contexts. Total extirpations of marine species are rare (Powles et al. In press, FAO 2000), and reflect failures in management or effects of environment change on a scale which clients would have hoped would have been detected much earlier. This tells is that diversity indices which weight richness much more strongly than evenness will insensitive, and miss many ecosystem changes short of total extinctions of many species. Therefore we should prefer indices emphasizing evenness. This requires, though, that our monitoring program will quantify all species in a sample with equal diligence. Moreover, if one is going to compare different sampling stations, the relative detectability of species must be stable across sites. Otherwise diversity or similarity metrics emphasising evenness (or dominance) will give many false alarms reflecting changes in species-specific q's across sites, not changes in communities. Many historic surveys have not had these properties, and the LMR monitoring programs must have substantial backing of taxonomic experts.

Another possible source of concern is that diversity indices intrinsically treat all species (or taxonomic units) as equally informative and equally interesting, with regard to community structure and community change. There are many contexts in which this assumption can be questioned in ecological studies (Cousins 1991). Given the selectivity of many fishing gears and strategies, the assumption may be even more questionable in investigations of exploited marine ecosystems.

Multivariate ordination metrics

Description: Ordination techniques are a class of multivariate techniques which place things in order (hence the name). In ecological applications the "things" are usually sites ordered by gradients in their species compositions (Gauch 1982, Jongman et al 1987, Digby and Kempton 1987), but samples from a single site over time can also be ordinated. The common feature of ordination methods is that a complex matrix; commonly rows as sampling sites (or times), columns as species, and cell entries as abundances of species j at site i; is reduced to small number of axes where sites with similar species compositions are close together and sites with very different species compositions far apart. Statistically independent gradients usually are represented as orthogonal ordination axes. This gives the scores for individual species or sites on the ordination axes some desirable statistical properties. However, if the species' distributions and abundances are influenced by two (or more) environmental factors which are themselves moderately correlated, many ordination methods tend to attribute most of the influence to only one of the environmental features, and split the influence of the other among multiple orthogonal axes.

Ecological interpretational usually is aided by ancillary information, for example data on oceanographic features, directed fishing effort, or bathymetry. The results of the ordination can then be regressed on the environmental factor hypothesized to cause the change in community structure (McRae et al. 1998). In fact, when data are available for an environmental covariate, the class of ordination methods known as direct gradient analyses (Whitaker 1967, Gauch 1982) can use that information directly in the simultaneous identification of underlying gradients of both species composition and environmental features. This emphasises the similarities between ordination methods and traditional regression analyses.

A key feature differentiating members of the class or ordination methods is the assumptions made about the underlying distributions of the abundances of species (that is distributions in the statistical sense), and the functional relationship between the species abundances and the underlying gradients. Principal components analysis (PCA) and its relatives (ex. principal coordinates analyses) are based firmly in least-squares regression (Jongman et al. 1987). It is necessary that the abundance data conform (possibly after transformation) to the assumption of normal error structure, that zero abundances are very rare, and that the gradient(s) be well sampled across their full range(s). As a consequence, PCA and its close relatives are only applicable when the ecological range sampled is fairly narrow, with similar species present over the full range of sites.

Correspondence analysis (CA) is a popular member of a class of ordination techniques which can be applied when the sampled sites cover a range of flora or fauna sufficiently broad that at any given site many species may be absent. Conceptually individual species are assumed to follow some lawful distribution (often Gaussian) along the underlying gradient(s) to be reconstructed. Species differ in their first moment on the gradient (mean position on the axis) and, depending on the method, may differ in their second moment (variance in abundance around the mean) as well. An individual species may be absent for some range along the axis, then increase in abundance, reach a peak at the "most preferred" position on the gradient, and then decrease in abundance, reaching zero for the remainder of the gradient. Species' distributions overlap along the gradient, so that by analyzing the co-occurrence of all species pairs algebraically or geometrically it is possible to order the sites, and space them among a gradient, so species follow a natural transition. As with PCA, it is possible to extract further gradients orthogonal to the initial one, each accounting for progressively less of the original variance in the raw data (Hill 1973b). Although generally used to capture community responses to environmental gradients such as moisture (Hill 1973b - terrestrial application) or bathymetry (Gomes 1993 – marine application), there is no conceptual impediment to applying the method to extract a gradient of time.

Although CA allows ordination analyses of sparse matrices and investigation of long ecological gradients, it is not without its problems. One must specify a common functional form for the distribution of the species, which must be cleanly monotonic for each individual species. To define the axes well, at least most of the species should have a different peak (preferred habitat) on each axes. When species differ in the variances of their distributions as well as their means, computations can become indeterminate (Hill 1974, Jongman et al. 1987). This becomes a serious limitation when a data set includes both common and rare species. Adequate sampling of the communities at all sites is also important, because sub-segments of a long continuum often are ordered by the overlaps of species where they are uncommon.

The strict linearity assumption of the PCA and CA methods led to the development of alternatives that allowed departures from this assumption. These are particularly relevant for monitoring studies where the sensitivity of species to disturbance may vary among species for life history reasons, and human impacts may interact with environmental forcing. Either process could result in non-linear responses of marine communities to fishing. These non-linear methods are less sensitive to differences among species in their breadths and shapes of distributions, but the maximum likelihood algorithms have some funny characteristics (Goodall and Johnson 1987) and results are very vulnerable to distortions arising from incomplete sampling of species composition at sites.

Non-metric scaling (MDS) provides another way to deal with problematic underlying distributions of abundances. With MDS the similarities or dissimilarities among sites are estimated using the weaker assumption that the rank order of abundance of a species across sites is informative, but the actual quantitative estimates of abundance may not be (Kruskal 1964, Boch 1987, McRae et al. 1998). MDS then seeks a representation of all cases contained in the full species by site matrix in a space defined by many fewer dimensions, but preserving as well as possible the (dis)similarities of cases in the smaller dimension space. This weaker assumption of ordinal rather than interval information greatly increases robustness in the face of irregular distributions of abundance and high sampling variance. As a result MDS has become a preferred technique for ecological ordinations of benthic and fish communities (Clarke and Ainsworth 1993, Cao et al. 1997a, McRae et al 1998). Enthusiasm for this flavour of ordination should be tempered, though, by results of simulations which show discriminatory power of MDS is lower than for methods making more demanding assumptions, in contexts where the assumptions are even approximately met (Campbell et al. 1991). Moreover, most MDS methods require specifying *a prior* the number of axes that exist and a starting configuration for patterns in the data. These *a priori* requirements create substantial opportunity for the analysts's preconceptions to influence, if not dominate, the analytical results. Moreove, they require selecting a measure of (dis)similarity, which brings in many of the concerns discussed in the previous section.

Canonical correlations analysis is a development of PCA-type eigenvector methods, in fact, to allow simultaneous extraction of sets of ordination axes from matrices of species abundances and environmental attributes, preserving comparable arrangements of cases in each set of dimensions (Pielou 1984, Gittens 1985). A parallel adaptation of CA, called canonical correspondence analyses, has been developed as well (Jongman et al. 1987), although applications to this method are uncommon. These canonical ordination techniques are extremely powerful method for relating community structure to environmental structure, and in theory could be applied to ecosystem monitoring data, using paired matrices of species abundances and oceanographic attributes. However, canonical correlations (and correspondence) analyses requires quite strong compliance with assumptions about form of the error distributions (normal), cannot tolerate a sparse data matrix, and have strict limits on the numbers of variables which can be analyzed (Cooley and Lohnes 1971, Jongman et al. 1987) . Together these statistical requirements have limited the usefulness of canonical analyses in ecological applications.

As an alternative to the strong assumptions of canonical correlations analyses, Clarke and Ainsworth (1993) proposed a method for empirically linking environmental variables to MDS results. In keeping with the ordinal assumptions of MDS, the approach uses rank correlations between the (dis)similarity matrix of species abundances and (dis)similarity matrices of various combinations of the environmental attributes. It selects the combination of environmental features whose (dis)similarity matrix has this highest rank correlation with the species abundance matrix, and finally presents an MDS ordination of the species abundance matrix along with an appropriate ordination of the selected environmental attributes. The method is computationally demanding, but is more likely to be compatible with the true distributional properties of the data sets.

Evaluation: For a number of reasons, ordination scores are not likely to be prominent products of an annual monitoring program. Many are technical problems with applying the methods to data from sampling marine communities. Whole classes of ordination methods will be inappropriate. We know from past survey work that many species are uncommon and subject to substantial sampling error, so zero abundances will be common, unless sampling effort is very intense. Also there are likely to be some extremely generalist species, with poorly defined distributional optima and occasional exceptionally high catches. There are also severe problems with standardizing the breadths of distributions of species, and of entire gradients (partly related to the need to make external decisions decisions about the amount of information gained from the turnover of a widely distributed species relative to one with a narrow breadth of occurrence).

Other problems are interpretational. Orthogonal ordination methods often partition the influence of a structuring influence that is moderately correlated with several other mutually independent influences into several pieces. This is of particular concern when a strong environmental signal affects both abundances and spatial distribution of many species, and partially selective fishing fleets respond to these changes. In an ecosystem where different fleets may target different species, and the abundances of target species may be influenced by different oceanographic factors, fishing effects may then be diffuse, and the ordination will appear to attribute most pattern to the best defined environmental factor.

Still other concerns arise because ordination methods do not stack up well on our signal detection tests. Ordination methods require a matrix of multiple samples, and monitoring programs can provide these, either in space or in time. However, neither way of approaching the ordination will give us sensitive and reliable metrics.

Suppose we ordinate all the multispecies samples in year one, and use that ordination space as our reference point. As each site is sampled into the future, we can track how its score moves in ordination space. When sites make big excursions, we have a big ecosystem change at those sites. Unfortunately, all ordination methods are variance-structuring tools, so the initial ordination will be dominated by the species that are most variable in the first year's sampling. If these are species whose abundances are highly variable in space and time, or have highly aggregated distributions so there is a lot of sampling error, ordinations will give lots of false alarms. On the other hand, there can be many misses. Species which were initially either uncommon everywhere, so they contributed little to the total community variance, or quite abundant and widespread but without clearly defined optima relative to other species or environmental gradients (depending on the method) will get little weight in the initial ordination axes. Hence major increases in rare species, or declines in common but eruptive species, will not show up as big excursions of sites in ordination space.

It is, of course, possible to use samples from a single site and ordinate the time sequence. If there were long-term trends, either driven by environment or incremental effects of anthropogenic perturbations (unsustainable fishing, habitat degredation, etc) they could be apparent in the ordination axes. Some axes might be uninformative because of the sorts of considerations in the previous paragraphs, but others might be quite informative. However, ordination tools require samples to outnumber variable, and the more flexible the methods, the more data are needed to resolve data structures robustly. Therefore, such analyses will begin to provide insights once the monitoring program has been in place for several decades.

Summary Metrics of community data

Intermediate between full multivariate representations of biological communities, and single-value condensations of species' occurrences or abundances into indices lie some metrics that aggregate information on the occurrences of many species into a single relationship. The two most common aggregate metrics are number (or sometime biomass) spectra and dominance curves. Both have been used in investigating the changes in ecosystems due to exploitation and pollution.

Size spectra first partition the sample of specimens into size classes, and then aggregate numbers in each size class across all species in a collection. The size spectrum refers to the smooth relationship of aggregate numbers (or, more commonly, log numbers) to size interval across the relationship of aggregate numbers (or, more commonly, log numbers) to size interval across the full sampled range. The size spectrum of a community was first inferred empirically (Sheldon et al. 1972) and then motivated by reasons based on ecological trophodynamic efficiencies. Details of the theoretical basis for why size spectra should be log-linear remain controversial, but the credibility of fundamental size-dependent community processes is well established (Platt 1985, Borgman 1987, Beyer 1989, Thibaux and Dickey 1993). The intercept of the size spectrum of a community is widely held to bear some lawful relationship with system productivity for the range of sizes considered, whereas the slope of the size spectrum reflects how biomass and abundance are lost, either through bioenergetic costs or through size-specific mortality. Those references present results of both empirical and theoretical studies of how the slope of the size spectrum should vary systematically with system productivity, rates of energy flow through the ecosystem, and rates of loss (mortality) from the system. Those biological processes ought to reflect the major modes by which environmental forcing can influence ecosystems; making it more or less productive, making bioenergetic transfers more or less costly, and increasing or decreasing natural mortality rates.

The applicability of size spectra to fish communities has also been well established (Murawski and Idoine 1992, Pope at al. 1987, Pope and Knights 1982, Gobert 1994, Rochet et al. 1997, Bianchi et al. In press). Fishing has two direct effects on the slope of the size spectrum of a community, as well as a number of possible indirect effects. Fishing selectively harvests the larger individuals of an assemblage first, and increases the mortality rate for all sizes taken by the fishing gear(s). Both of those effects cause the slope of ln(numbers) to increase with fishing pressure (i.e. numbers by size class decrease faster with higher mortality).

This relationship was clearly shown in both survey data and model results for the North Sea, in work begun by the ICES Ecosystem Effects of Fishing Working Group (ICES 1995a,b 1996) and expanded by Rice and Gislason (1996). Gislason and Rice (1998) and Gislason and Lassen (1997) went on the investigate the theoretical basis for this relationship, in a simulation framework using multispecies virtual population analysis (MSVPA; Gislason and Helgason 1985, Sparre 1991) with some length based assumptions about growth and mortality (Sparre and Venema 1992). The simulations showed a direct functional relationship exists between f and both the slope and intercept of the size spectrum; as systems are fished harder the spectrum slope gets steeper (biomass or numbers are lost faster), and the intercept gets higher (more of the biomass or numbers is in small size classes than is the case in a lightly exploited system). This relationship was insensitive to the value assumed for natural mortality, and robust to alternative assumptions about the effect of spawning stock biomass on recruitment. These results make these two parameters attractive metrics for impacts of fishing on fish assemblages.

Some of the papers on size spectra also explored the spectrum of diversity by size class, for the same North Sea survey data and models. The expected patterns of diversity across sizes of organisms in a community have not received much attention from theorists, but the patterns could have some important implications (Cousins 1991, Tothmeresz 1995). As expected given the log-linear decrease in abundance with size, size-specific diversity also decreased with size category. However, the overall pattern was dome-shaped, with the highest diversity always at size classes about 20-30% up the range of sizes considered. The lower diversity at the smallest sizes considered is an artifact to some extent; in the survey data because small fish are not completely vulnerable to the survey gears, and in the simulations because the models contain nearly all the large species regularly present in the data used for parameterization, whereas a larger proportion of small species are not included in the models.

Dominance curves present the species in a community or collection ranked by their abundances. They have been proposed as tools to conduct abundance-biomass comparisons across communities; hence the alternative name ABC curves. A variety of transformations of both the rank species axis and the abundance axis have been proposed at various times (Beukema 1988, Clarke 1990), although the transformations largely change the visual representation of information and not the nature of the information being presented. Like size spectra, it is the full shape of the curve (or parameters from which the shape may be reconstructed) which contains information about the community under study.

In many applied contexts the k-dominance curves have been adopted as a community metric. These present cumulative ranked abundance plotted against the log of species rank (Lambshead et al. 1983). The logic behind using k-dominance curves to evaluate ecosystem effects of perturbations is similar to the logic behind using univariate diversity indices: perturbations cause a subset of species which tolerate the perturbation to thrive, while many other intolerant species either disappear or become very rare. Such changes would make k-dominance curves of perturbed communities lie above and to the left of the curves of unperturbed communities. Similar *a priori* predictions can be made about the differences between perturbed and unperturbed communities with other variants of abundance-biomass-species rank graphs. The thought and simulation investigations of how dominance curves change with increasing perturbation were developed for pollution, where a small number of species are often highly pollution-tolerant, and most others decline in abundance. To the extent that fisheries are species selective, and exploit a sample of the total community biased towards higher productivity, they will also have predictable impacts on dominance curves.

Evaluation: This class of metrics stands up well to our criteria. They can be estimated annually for a sample (assuming it contains enough data to be worth analyzing on its own), or for the collection or samples. Samples over time can be contrasted after a program has been in place for only a few years, rather than a few decades.

Changes in overall productivity, transfer efficiency, or mortality rate of the parts of the ecosystem being sampled should be detected by size spectra methods, without being inflated or buffered by assumptions regarding what is going on in parts of the ecosystem not being monitored. Because spectra are calculated from log numbers by size class across all size classes, distortions due to occasional strong years classes of one or a few species will be less than with many of the diversity metrics, so there should be fewer false alarms. If strong recruitments are maintained over several years, without concomitant decreases in other species, this *is* an increase in system productivity, and should affect the metric's value. The same is true, although possibly to a lesser extent, for dominance curves. They may become more markedly humped if one species has a very strong year-class, but unless productivity and survivorship of the rest of the species being sampled is affected at the same time, all but the left-most part of the curve is likely to remain fairly stable.

Both summary metrics will miss high turnover rates of uncommon species, whose meta-populations may be flickering without affecting these metrics greatly. However, without special planning most monitoring programs are not going to sample uncommon species reliably, so the "ecosystem change being missed may be as much sampling error as true ecosystem change. If the monitoring program is expected to capture relative abundance of uncommon species well, species replacements will be invisible to these methods. However, losses in overall richness due to many uncommon species becoming even rarer will be captured well by dominance curves, and if they are large individuals (which often have vulnerable life histories) they will be captured by size spectra as well.

It is also useful that some well developed theory is available, supported by simulations, to link fishing and environmental forcing directly to size spectra metrics, and environmental change directly to dominance curves. This work provides a valuable framework for interpreting metrics of behaviour.

Spectra of size-specific diversity are less promising. Due to artifacts pointed out above the ascending limb of diversity spectra is sensitive to both relative catchabilities of species partially recruited to the sampling gear, and their production of large year-classes. Moreover, neither the simulations nor the analyses of the empirical survey data found any systematic changes in the slope of the descending limb of the diversity spectra over a range of intensities of mortality. Although the analyses of the slopes of the diversity spectra of survey data could not reject the hypothesis that communities may be responding to fishing in ways which conserved size-specific diversity, the models had no such compensatory processes (Rice and Gislason 1996, Gislason and Rice 1998). Hence it seems that at least the size-specific diversity of a community is not going to be a sensitive indicator of system change.

"Emergent property" metrics

All previous metrics are direct representations of data on the occurrences or abundances of various species in a community (or, more properly, samples from that community). These data are simply subjected to some statistical treatments; aggregated to various degrees, or arranged on various latent axes. The final class of metrics of community status move beyond aggregating or ordinating data, to reflect some hypothesized underlying properties of the community or ecosystem. These properties require the intervention of some form of ecological model, in each case representing hypotheses about the trophic interactions among species or species groups in the model. The question of how well the metric reflects a core property of the ecosystem cannot be disassociated from the question of how well the model represents the ecosystem. It is beyond the scope of this paper to evaluate critically the merits of various ecosystem modeling approaches, but some general families can be summarized briefly. The summaries will focus on properties of the models that are relevant to the possible role in monitoring programs and as indicators of ecosystem or community status.

Mass Balance models are one well established class of ecosystem models (Pauly and Christensen, Walters etc). Within this modelling framework, biomass and energy flow are to be fully accounted for at all trophic levels, allowing changes in populations due to predators or fisheries to be expressed in the common currency of the proportion of primary production required to sustain the removals regardless of trophic level (Pauly and Christensen 1995). Key properties of the models which are argued to reflect the dynamics of transfer efficiencies, cycling rates, and path lengths, include throughput (a flow volume metric), ascendancy (a flow structure metric), developmental capacity (the cap on ascendancy) and redundancy (a metric of alternative pathways) (Ulanowicz 1997, Baird and Ulanowicz 1993). Building on this foundation of full ecosystem metrics, within the model several metrics can be used to changes directly: These include primary production required to support fisheries (or top predators), the mean trophic level at which the fishery operates, and the transfer efficiency between trophic levels (Jarre-Teichmann 1995, 1998, ICES 1999). The first two measure changes in populations at various trophic levels directly; the third measures the change in the production to biomass ratios of all species in the ecosystem, using again the long-established concept that as total mortality of a guild increases, standing stock is reduced and productivity is increased - at least up to a point at which the stock collapses.

Food web models have some similarities to mass-balance models, but usually they do not represent the biomass in each node, nor estimate directly the magnitude of flow among nodes. Rather, they focus on representing fully all possible predaton pathways among nodes, and evaluate the sensitivity of various properties of the web to alternate configurations. Key properties analyzed include stability of the configuration (can all nodes persist) and resilience to perturbations such as invasion by a new species or loss of one or more nodes. Pimm (1982) provides a thorough treatment of this class of models. This modelling framework has been tied to the long ecological debate about the inter-relationships of diversity and stability of communities, summarized in Pimm (1991) and Rosenzweig (1995).

Several studies have used this food web modelling framework to evaluate the impacts of fisheries on the model systems (Pimm and Hyman 1987, Pimm and Rice 1987, Yodzis 1988, 1994). Within this modelling framework, questions on effects of fisheries are framed around the persistence of the original community configuration when a fishery establishes itself as an additional node with new linkages to existing species (nodes) in the web. Hence the community metrics are the ones typical of this approach; stability or persistence of a configuration over time. Both Yodzis (1988, 1994) and Pimm and Rice (1987) have highlighted limitations of this approach for investigating dynamics of marine ecosystems; the former through attention to the indeterminacy of model representations of systems of even moderate complexity, and the latter through the documentation of the domination of life-history linkages within species over trophic linkages between species in terms of influences on model properties.

Neither the mass-balance nor the food-web modelling approaches readily accommodate the role of external forcing functions on the trophodynamic system. The trophic cascade modeling approach, developed for application in freshwater lakes, however, gives great emphasis to differentiating top-down from bottom-up effects (Carpenter 1988, Carpenter and Kitchell 1988, Carpenter et al. 1985, McQueen and Post 1988, Christoffersen et al 1993, Schindler et al. 1993). Structurally, these models have many similarities with the general class of food web models described above, but often with more accounting for biomass at various trophic levels. Hence the metrics of community status can be both measures of transfer from trophic level to level, and the standing biomass at the various levels. The price paid for being able to consider both bottom-up and top-down forcing, though, is the need to have the structure of the system very tightly constrained. This has been achieved in studies of lacustrine systems (ex. Carpenter 1988, Martin et al.. 1992), but it becomes difficult to constrain even enclosed coastal areas (Hansson 1985, Hansson et al. 1998). Further development of this framework will be required before its utility in evaluating effects of large marine fisheries can be assessed (ICES 1999).

Commentary on using modelling to detect change

Although numerous publications promote the use of one set of model-based metrics or another to marine ecosystem dynamics, no comparative studies have documented the relative sensitivity or reliability of metrics from the various modeling approaches. Christensen (1995) contrasted the ability of mass-balance and multi-species VPA approaches to represent the North Sea, but did not contrast summary metrics of the two modeling approaches on criteria relevant to this work. Without comparative studies of metrics from different modelling approaches, comparisons can only be based on the properties of the conceptual frameworks underlying the modelling approaches. . Accepting a modelling framework means accepting the ecological theory behind it.

With regard to the modelling frameworks, there is no shortage of unresolved controversy. Several of the modelling frameworks give competition a strong role in structuring ecological communities. In a strong competition framework, any process, including environmental forcing and fishing, which changes the abundance of one species necessarily produces reciprocal changes in the abundance of competitors.

The role of competition in even terrestrial ecosystems has been debated for decades, and no resolution is in sight (Cody & Diamond 1975, Strong et al. 1984, Yodzis 1989, Rosenzweig 1995). Both mass-balance and trophic-cascade models include a prominent role for competition, through balancing flows through each trophic level. MSVPA gives competition a variable role, depending on assumptions made about "Other food" and about recruitment processes when MSVPA run in the forecast mode. It was observed long ago that proponents of strong competition tend to have worked with higher vertebrates, whereas proponents of a weak role for competition and a strong role for environmental forcing have tended to work with insects or other invertebrates (Andrewartha and Birch 1954, Tilman 1982). In terms of life histories, a large proportion of the fish and invertebrates likely to be featured in our monitoring resemble invertebrates more than birds and mammals, although there are important exceptions. Correspondingly, there is substantial evidence of environmental forcing playing a very strong in marine ecosystems, and species with important middle trophic roles can have large variations in abundance for reasons other than predation (Bakun 1996, Rice 1995, Cury & Roy 1989, Cury et al. In press). Modelling frameworks which do not accommodate large magnitude dynamics from non-trophic sources are going to provide at best limited insight into the responses of marine ecosystems to perturbations by fisheries.

There are other factors that are relevant to the appropriateness of various modelling frameworks to evaluate the responses of marine ecosystems to perturbations. Simulations have suggested that even moderate fishing mortalities can eliminate much of the evidence of competition between pairs of species, by reducing the abundance of species regardless of their competitive abilities (Rice and Kronlund 1998). It is true that *some* populations may (according to strong competition linkages, "must") increase in abundance when fishing depresses the abundances of target (and bycaught) species, and that competition theory may provide insight into which species. However, these complex and indirect competitive interactions are known to be indeterminate (Yodzis 1988, Polis et al. 1989) and unpredictable at the species level.

The complex life histories of fish and marine invertebrates has another implication for trophodynamic models of marine ecosystems. Many species actually fill several different trophic roles at different life history stages. The model formulations of the trophic transitions can have a bigger impact on model stability and persistence than the formulations of predation and competitive interactions (Pimm and Rice 1987). The relative impact of the formulations of the two types of processes on model flow dynamics has not been studied. Nonetheless, for ecosystems where many species show life history omnivory, credible models must address the life-history transitions with functional processes as fully thought out as the predator-prey dynamics.

This commentary on ecosystem models does little to resolve which of their metrics are most appropriate for evaluating the ecosystem effects of fishing. Rather, the commentary highlights some properties missing in most of the ecosystem modelling approaches being applied at present. Accepting any of their metrics as indicators of ecosystem change implicitly also accepts either that one is confident that processes like environmental forcing of recruitment and survivorship variation, and trophic life history transitions are unimportant in the system under study, or that the modelling framework has the processes captured adequately elsewhere. For example, the size-based transitions of the size spectrum approaches may offer some hope here, but such approaches need much more thorough investigation.

Evaluation: It is long established that modelling has an important role in designing research questions, refining hypotheses to be tested, and revealing new questions to be asked. These functions make modelling very important at early stages in a long-term program, to help make sure the field studies collect the most important data for increasing knowledge of the systm being studied, and at the end, to synthesize diverse results, and convert data into information, knowledge, and understanding. Modelling can make contributions during a long-term study as well. As data accumulate, hypotheses can be refined, and as data begin replace hypotheses about things which were largely unknown at the beginning of a long-term study, new, better focused questions can be formulated. Such modelling allows field programs to adapt to accumulating knowledge. All these features are great virtues of models, as long as the model makes biological (and, where relevant physical, chemical, social, and economic) assumptions appropriate to the system being studied.

The above endorsement of modelling in long-term studies did not identify particular model-based metrics to be part of the routine results of monitoring programs. That was intentional, because I do not feel model-based parameters will have the desirable high hit rates, and low rates of misses and false alarms, with regard changes ocurring in the system being monitored. This is a personal judgment, and to my knowledge the right kinds of investigations have not been performed to quantify hit, miss and false alram rates for models. I'll explain the basis for my judgment discussing experience with a particularly simple modelling framework, and subsequently extrapolate that experience to possible implications for other modelling approaches.

MSVPA is a very simple modelling framework, at least scientists with backgrounds in fisheries. It uses the same formulations of population dynamics used in single-species SPA, with predation of specified predators and prey added explicitly. Two key artificial constraints are added: that all predators obtain their full annual ration, and that the amount of "other prey" in the ecosystem has some fixed property. Options for the latter were thoroughly explored in simulations: other food constant, other food a constant percentage of prey explicitly in the model, or total food in the ecosystem is constant; and the consequences of each assumption are known [Sparre 1991). Otherwise age-structured species interactions are modelled explicitly, whereas, as in SPA there is no attempt to model processes like recruitment of species-environment interactions internally to the model. Rather these dynamics are put in from outside the model itself (Gislason 1991). The model also needs very little data by ecosystem modelling standards; only typical age structured catch data for the species explicit in the model, and age or size structure diet data for the predators and prey explicit in the model.

To some, MSVPA does not appear "simple" nor modest in its data requirements. However, in contrast to other ecosystem models, MSVPA only requires data on a small number of predators and prey, and claims to represent very few processes dynamically. The price, of course, is that it does not provide any insight into parts of the ecosystem not represented explicitly. Even with these simplifications of structure and data requirements, however, experience with MSVPA led to the conclusion that it was not worthwhile to rerun MSVPA more often than about every 5 years with updated population data, and at most once a decade with new diet data (ICES 1994, 1997). This inertia in model outputs was partly due to inertia in the age structured catch data (a phenomenon familiar to anyone working with age-structured assessment models) and partly that the species interaction dynamics were changing more slowly that the species' abundances (Rice et al 1991, Rindorp et al. 1998).

The above conclusions arose from applications of MSVPA to the highly reticulate and relatively stable North Sea. When MSVPA was applied to the Barents Sea, where variability of species abundances due to environmental conditions is much greater, key changes were necessary, such as replacing the constraint that all predators fulfilled their annual ration, with variable annual realized ration. Ideally this variable ration could be modelled relative to environmental conditions, but in practice it was tied to inter-annual differences in growth rates of key predators (assuming that inter-annual differences in food consumed translated into differences in growth). Used this way MSVPA could still provide useful estimates of predation mortality and total consumption of prey in the model, but it still required inputting the ecosystem dynamics from outside the model. Therefore, it did not reveal any changes that were not input to the model itself. Any major changes which would be the basis for judging hit, miss and false alarms would already be present in the growth rate data and the catch data. The changes would only be smoothed by the use of diet data aggregated over more than single years, and the model's need to give cohorts stable behaviour along the diagonal. Analyzing the external data directly should always give more sensitive indications of change than analyzing emergent properties of the of even the relatively more dynamic boreal MSVPA (of which there are many choices).

Valuable lessons should be taken from the experience with MSVPA. Ecosystem models that attempt to represent even more parts of the ecosystem are usually going to be even less able to detect changes in information being generated by feasible monitoring programmes. Mass balance models with most or all trophic levels presented commonly require taking data of highly variable reliability from diverse sources. The mass-balance models themselves then determine how the various data sets of biomasses and transfer rates differentially influence both first order model estimates (the biomasses and transfers estimated from the family of linear equations, once 50%+1 of these have been fixed) and aggregate ecosystem metrics constructed from the first order estimates. This is not a new insight; conducting sensitivity analysis of parameters of complex models is basic good practice in modelling. The thing to focus on is that the differential sensitivity (in the model sensitivity analysis context) has consequences for sensitivity in the signal detection context. In the case of the Newfoundland and Scotian Shelf ecosystems this was clear in the presentations made at the December 1998 workshop on seal consumption estimates (CSAS Proceedings 1999), where some of the most poorly resolved parts of the ecosystem turned out to have high leverage in a allowing a set of all-positive parameters to be found.

Not only may the differential initial weightings of input information used by ecosystem models affect output metrics in ways which may make them overly sensitive to variation in some inputs, and insensitive to other variation, but a monitoring program is not going to allow all inputs to be updated annually. This means that the signal in the annually updated biomasses or flows will be buffered by all the other input biomasses and flows which are not changed annually, because there are new data with which they can be updated. These conditions almost ensure that emergent properties of these ecosystem models will issue lots of false alarms and commit lots of misses, if recalculated annually. Signals of changes in ecosystem components may be smoothed out by the buffering effect of all the model components which are not updated with the new monitoring results, and inter-annual variance in inputs to which model parameters are highly sensitive could lead to emergent properties undergoing deceptively large excursions. These problems, of course, are superimposed on the structural problems of ecosystem models discussed in the commentary section; that ecosystem models generally do not model life history trophic transitions at all (let alone correctly), handle ecosystem forcing poorly or not at all, and if food webs are reticulate, proper representations of relationships are indeterminant.

In summary, ecosystem modelling will have a very important role in design of a monitoring program, in bringing results together once the program has been underway for a decade or more, and to some extent for keeping the program on track in between. Summary metrics emerging from the models are not going to be reliable, sensitive metrics of ecosystem status and ecosystem change on an annual basis, however. The wiser strategy is to run these models about once a decade, reparameterized as fully as possible each time, and contrast metrics from those different ecosystem configurations. Looking back at the accumulated data, short intervals during which regime shifts may have occurred may be apparent. In such cases, they represent logical dividing points for separate parameterizations of ecosystem models and estimation of new values for the emergent metrics. But I think experience shows that these abrupt changes will be apparent sooner in the monitoring data themselves than in the values of annually revised metrics of emergent properties.

Summary / Conclusions

1. For communication of the state of a system being monitored to other experts many community and ecosystem metrics can be used, as long as adequate explanations of the methods used to compute the metric are given.
2. For detection of changes in ecosystem, or differences between ecosystem, usefully sensitive metrics will have high hit rates, and low rates of misses and false alarms. When they occur misses and false alarms may have very different consequences, and perception of costs may differ among individuals and groups.
3. Diversity indices and ordination metrics may have high error rates under realistic conditions. Ordination techniques, in particular, may be useful at the end of an interval of monitoring, but less so on a regular basis during it.
4. Summary metrics of data sets, such as size spectra and dominance curves, are likely to have the lowest rates for both misses and false alarms, but are not expected to perform without errors in all circumstances.
5. Models have many roles in design, summarization and guiding monitoring programs. However, emergent properties of models are not good candidates as routine metrics for detecting ecosystem changes as monitoring proceeds. Many models will have serious limitations for all applications.
6. Interpreting all ecosystem metrics is difficult or impossible without reference to the data that went into their calculation. In many uses, particular communicating with non-specialists, the interpretation of the data make the ecosystem metric itself superfluous.

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10 Addendum

Subsequent to the LMR-GOOS workshop, a workshop was held June 19-23, 2000 at BIO on Ecosystem Considerations for the Eastern Scotian Shelf Integrated Management (ESSIM) Area (O'Boyle, 2000). Among the topics considered at this workshop were the six ecosystem objectives and indicators discussed at the LMR-GOOS meeting. The issue of terminology was brought up, e.g. the appropriateness of the term "ecosystem objective" was questioned. Additionally, refinements in descriptors for the various ecosystem objectives were proposed. For example, Ecosystem Objective #1, "Ecosystem Diversity" was considered to be ambiguous and might be more appropriately called "Diversity of Ecosystem Types". In general, a recommendation was made that each of the ecosystem objectives be clearly defined in such a way as to be understood easily by lay persons as well as science professionals. A suggestion was also made that a 7th ecosystem objective dealing with marine environmental quality should be added.

In February (19-21) 2001, A DFO National Monitoring Workshop was held to: (1) review existing monitoring programs within DFO and identify successful practices as well as problems, (2) determine common elements and rationalizations for region-specific elements, (4) identify observational gaps, (5) review data products being produced and how knowledge gained is communicated to internal and external clients and identify successes, problems and opportunities for improvement. GOOS and Arctic monitoring plans were reviewed to insure that they adequately reflect new DFO requirements to meet international obligations and national requirements related to management through ecosystem objectives, aquaculture development and integrated management.

A National Workshop on Objectives and Indicators for Ecosystem-based Management was convened 17 February – 2 March, 2001 as a follow-up to the LMR-GOOS and ESSIM workshops to further refine the ecosystem objectives framework and to provide a mechanism for operationalization of ecosystem-based management nationally (Jamieson et al. 2001).

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